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Yoshioka

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(45) **Date of Patent: Oct. 18, 2016**

(54) **FAILURE DETECTION DEVICE FOR EXHAUST RECIRCULATION APPARATUS OF ENGINE WITH SUPERCHARGER**

(71) Applicant: **AISAN KOGYO KABUSHIKI KAISHA**, Obu-shi, Aichi (JP)

(72) Inventor: **Mamoru Yoshioka**, Nagoya (JP)

(73) Assignee: **AISAN KOGYO KABUSHIKI KAISHA**, Obu (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 66 days.

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(30) **Foreign Application Priority Data**

Jul. 8, 2013 (JP) 2013-142664

(51) **Int. Cl.**

F02B 33/44	(2006.01)
F02B 37/00	(2006.01)
F02M 25/07	(2006.01)
F02B 37/18	(2006.01)

(52) **U.S. Cl.**

CPC ***F02M 26/49*** (2016.02); ***F02B 37/00*** (2013.01); ***F02M 25/0702*** (2013.01); *F02B 37/18* (2013.01)

(58) **Field of Classification Search**

CPC ... F02B 37/00; F02B 37/18; F02M 25/0702; Y02T 10/121

See application file for complete search history.

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Primary Examiner — Jesse Bogue

(74) *Attorney, Agent, or Firm* — Oliff PLC

(57) **ABSTRACT**

In an engine with a supercharger, a low pressure loop EGR apparatus includes a EGR passage to allow part of exhaust gas discharged from a combustion chamber of the engine to an exhaust passage to flow as EGR gas in an intake passage to return to the combustion chamber, and a EGR valve to regulate a flow of EGR gas in the EGR passage. The EGR passage has an inlet connected to the exhaust passage downstream of a turbine and an outlet connected to the intake passage upstream of a compressor. An ECU controls the EGR valve while the engine is in a predetermined operating condition, and determines whether or not the EGR valve is failed based on changes in intake amount in the intake passage during control of the EGR valve.

9 Claims, 17 Drawing Sheets

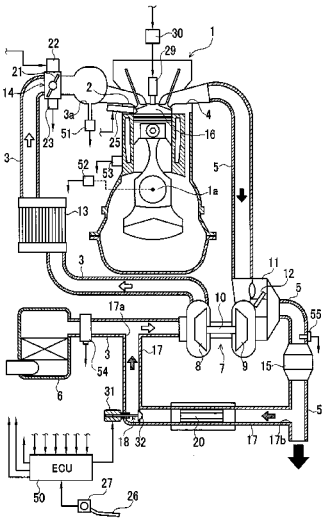

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FIG. 1

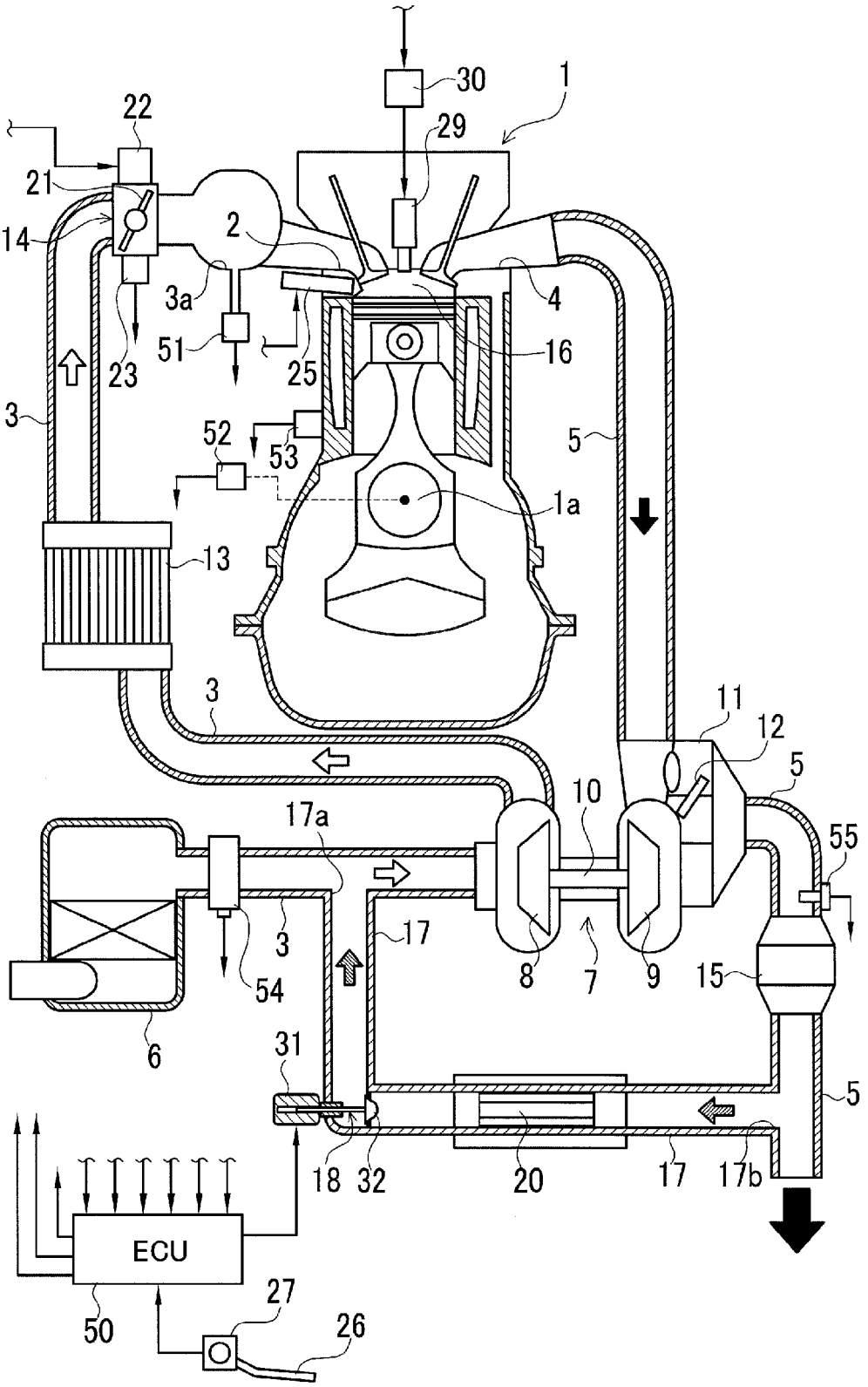

30
1
22
29
21
2
14
3a
4
51
23
25
16
3
52
53
5
1a
13
3
11
12
5
10
17a
55
3
17
54
8
7
9
15
6
31
5
18
32
20
17
17b
ECU
27
50
26

FIG. 2

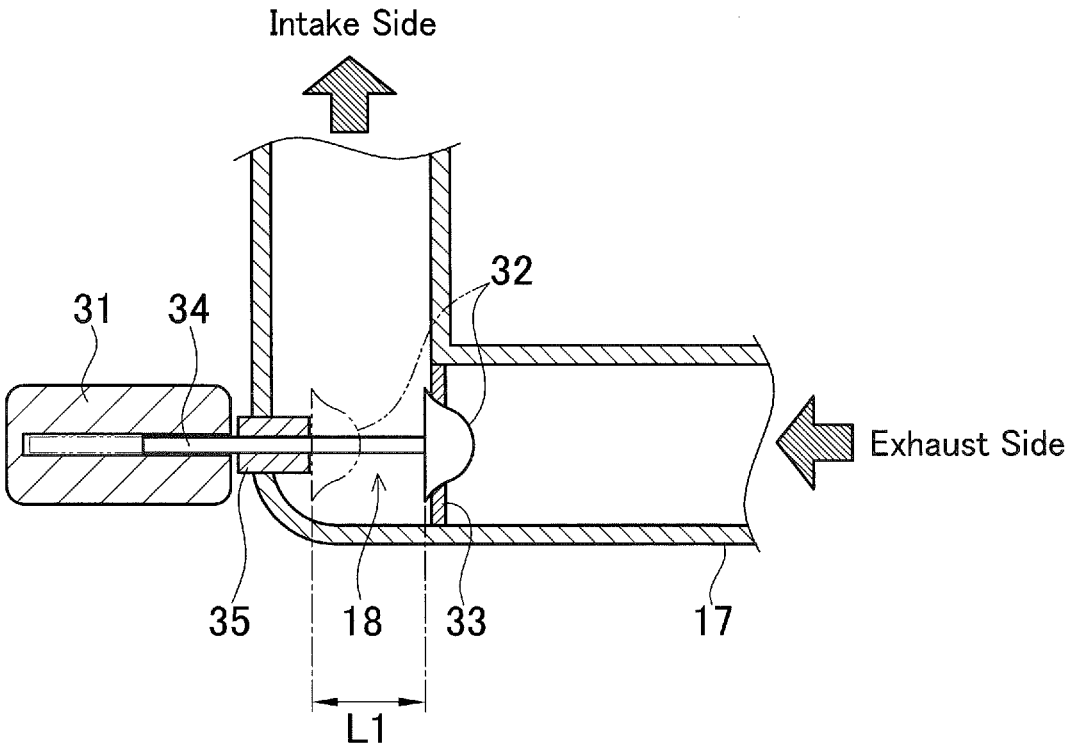


FIG. 3

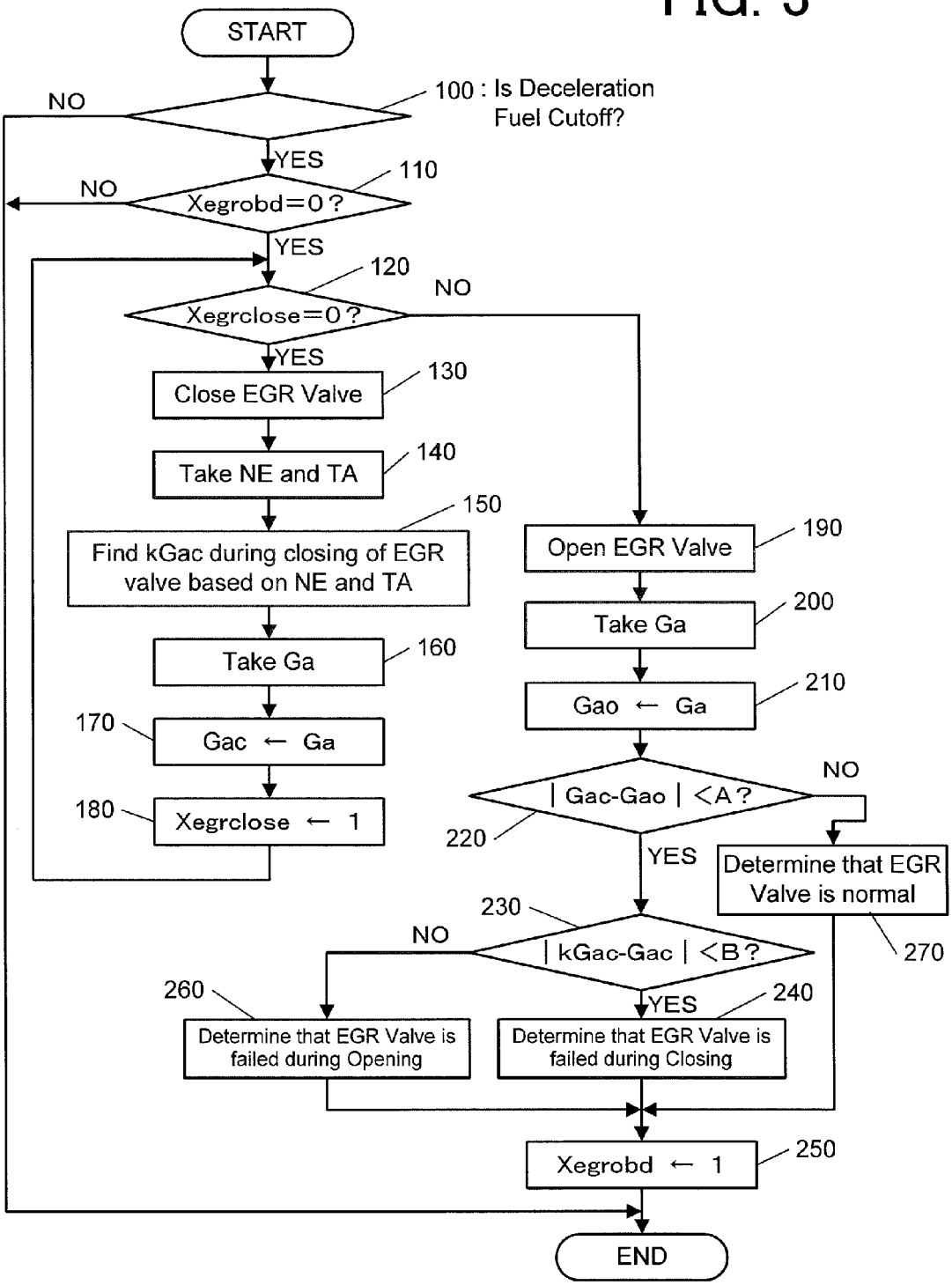
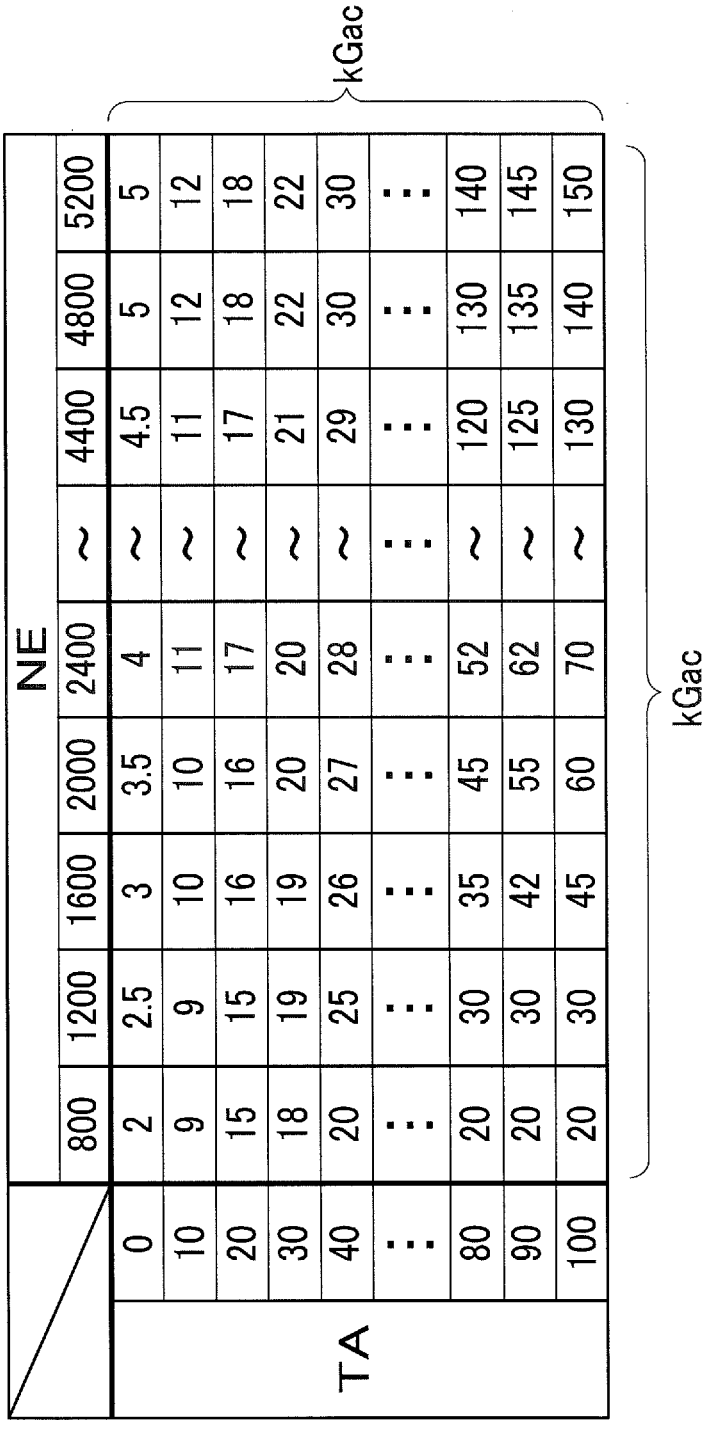

START
100 : Is Deceleration Fuel Cutoff?
NO
YES
110
Xegrobd=0?
NO
YES
120
Xegrclose=0?
NO
YES
130
Close EGR Valve
140
Take NE and TA
150
Find kGac during closing of EGR valve based on NE and TA
160
Take Ga
170
Gac ← Ga
180
Xegrclose ← 1
190
Open EGR Valve
200
Take Ga
210
Gao ← Ga
220
| Gac-Gao | <A?
NO
YES
Determine that EGR Valve is normal
270
230
| kGac-Gac | <B?
NO
YES
240
260
Determine that EGR Valve is failed during Opening
Determine that EGR Valve is failed during Closing
250
Xegrobd ← 1
END

FIG. 4



TA \ NE	800	1200	1600	2000	2400	~	4400	4800	5200
0	2	2.5	3	3.5	4	~	4.5	5	5
10	9	9	10	10	11	~	11	12	12
20	15	15	16	16	17	~	17	18	18
30	18	19	19	20	20	~	21	22	22
40	20	25	26	27	28	~	29	30	30
...	...	...	...	...	...	...	...	...	...
80	20	30	35	45	52	~	120	130	140
90	20	30	42	55	62	~	125	135	145
100	20	30	45	60	70	~	130	140	150

FIG. 5

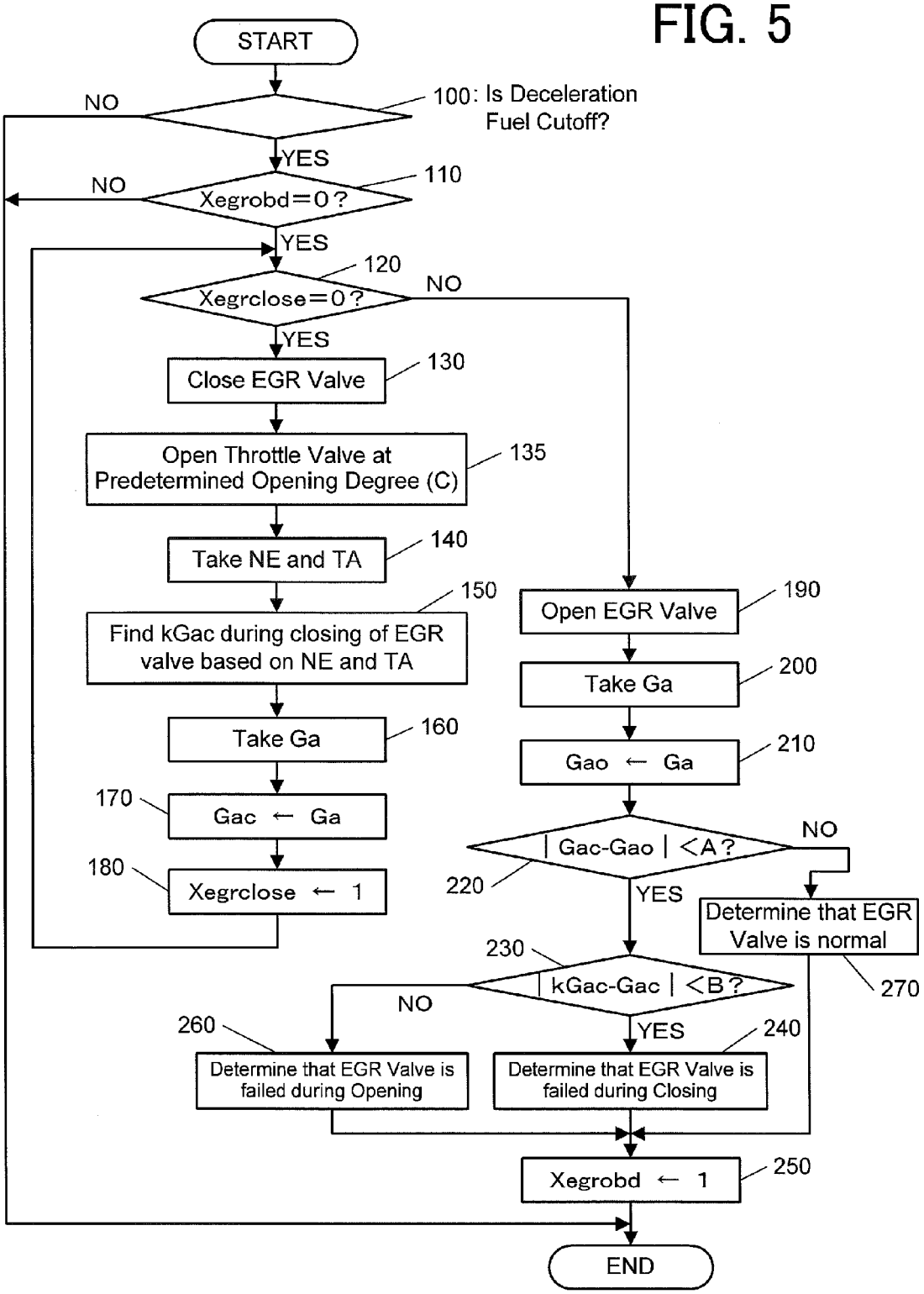

START
100: Is Deceleration Fuel Cutoff?
NO
YES
110
Xegrobd=0?
NO
YES
120
Xegrclose=0?
NO
YES
130
Close EGR Valve
135
Open Throttle Valve at Predetermined Opening Degree (C)
140
Take NE and TA
150
Find kGac during closing of EGR valve based on NE and TA
160
Take Ga
170
Gac ← Ga
180
Xegrclose ← 1
190
Open EGR Valve
200
Take Ga
210
Gao ← Ga
220
| Gac-Gao | <A?
NO
YES
Determine that EGR Valve is normal
270
230
| kGac-Gac | <B?
NO
YES
260
Determine that EGR Valve is failed during Opening
240
Determine that EGR Valve is failed during Closing
250
Xegrobd ← 1
END

FIG. 6

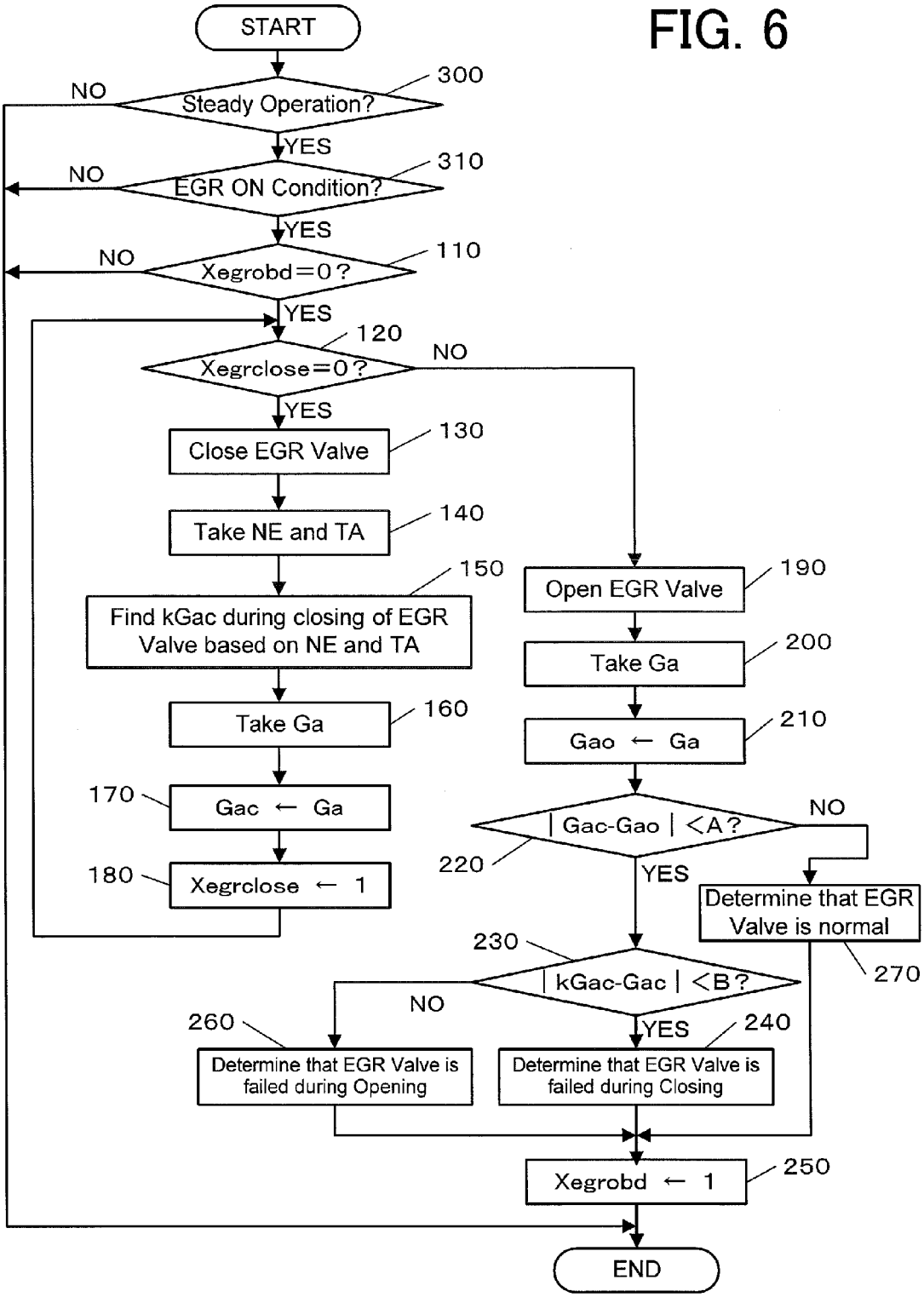

START
Steady Operation?
300
NO
YES
EGR ON Condition?
310
NO
YES
Xegrobd=0?
110
NO
YES
Xegrclose=0?
120
NO
YES
Close EGR Valve
130
Take NE and TA
140
Find kGac during closing of EGR Valve based on NE and TA
150
Take Ga
160
Gac ← Ga
170
Xegrclose ← 1
180
Open EGR Valve
190
Take Ga
200
Gao ← Ga
210
| Gac-Gao | <A?
220
NO
YES
Determine that EGR Valve is normal
270
| kGac-Gac | <B?
230
NO
YES
Determine that EGR Valve is failed during Opening
260
Determine that EGR Valve is failed during Closing
240
Xegrobd ← 1
250
END

FIG. 7

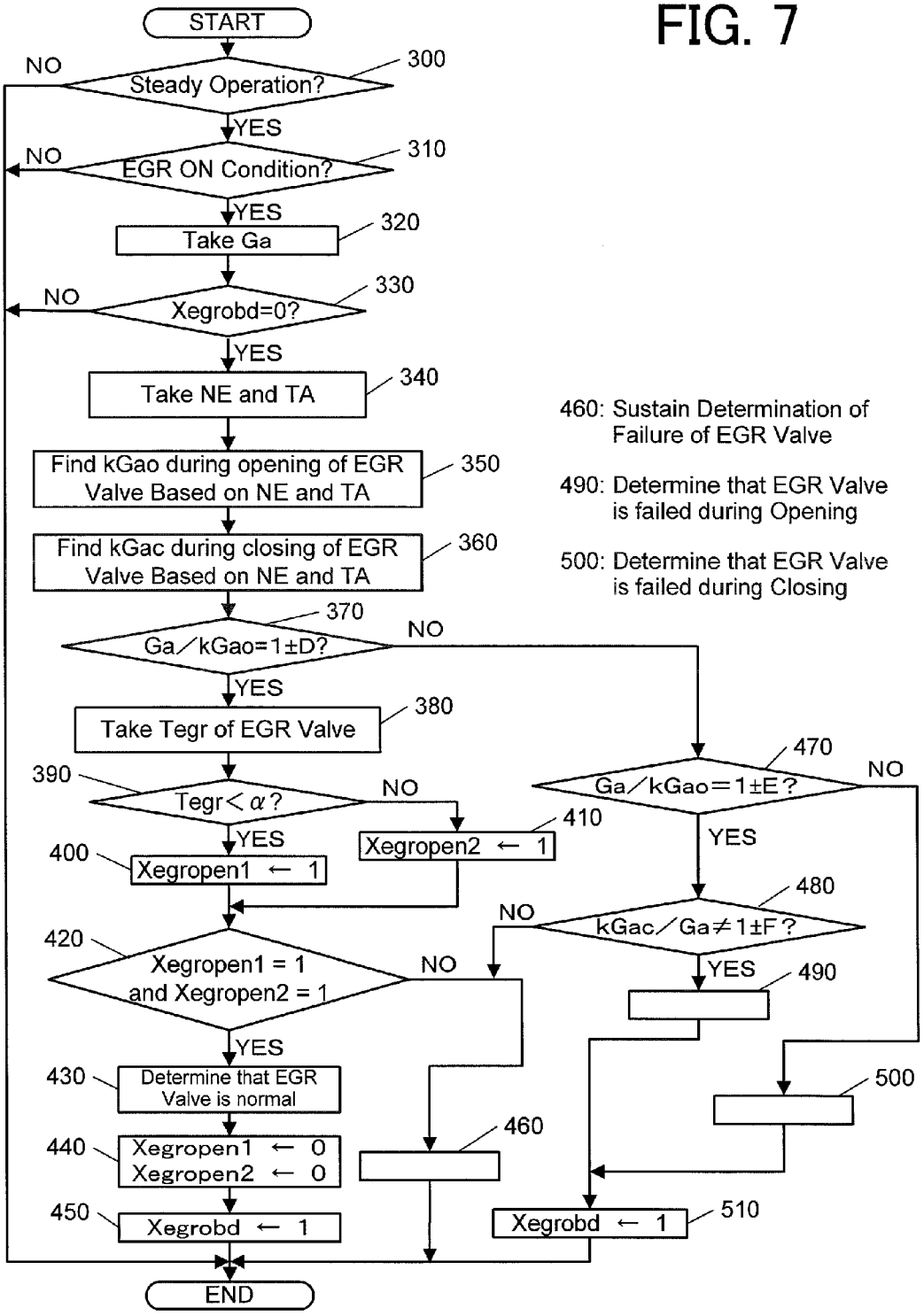

START
Steady Operation?
NO
YES
300
EGR ON Condition?
NO
YES
310
Take Ga
320
Xegrobd=0?
NO
YES
330
Take NE and TA
340
Find kGao during opening of EGR Valve Based on NE and TA
350
Find kGac during closing of EGR Valve Based on NE and TA
360
Ga／kGao=1±D?
370
NO
YES
Take Tegr of EGR Valve
380
Tegr＜α?
390
NO
YES
Xegropen1 ← 1
400
Xegropen2 ← 1
410
Xegropen1 = 1 and Xegropen2 = 1
420
NO
YES
Determine that EGR Valve is normal
430
Xegropen1 ← 0
Xegropen2 ← 0
440
Xegrobd ← 1
450
460
Ga／kGao=1±E?
470
NO
YES
kGac／Ga≠1±F?
480
NO
YES
490
500
Xegrobd ← 1
510
END
460: Sustain Determination of Failure of EGR Valve
490: Determine that EGR Valve is failed during Opening
500: Determine that EGR Valve is failed during Closing

FIG. 8

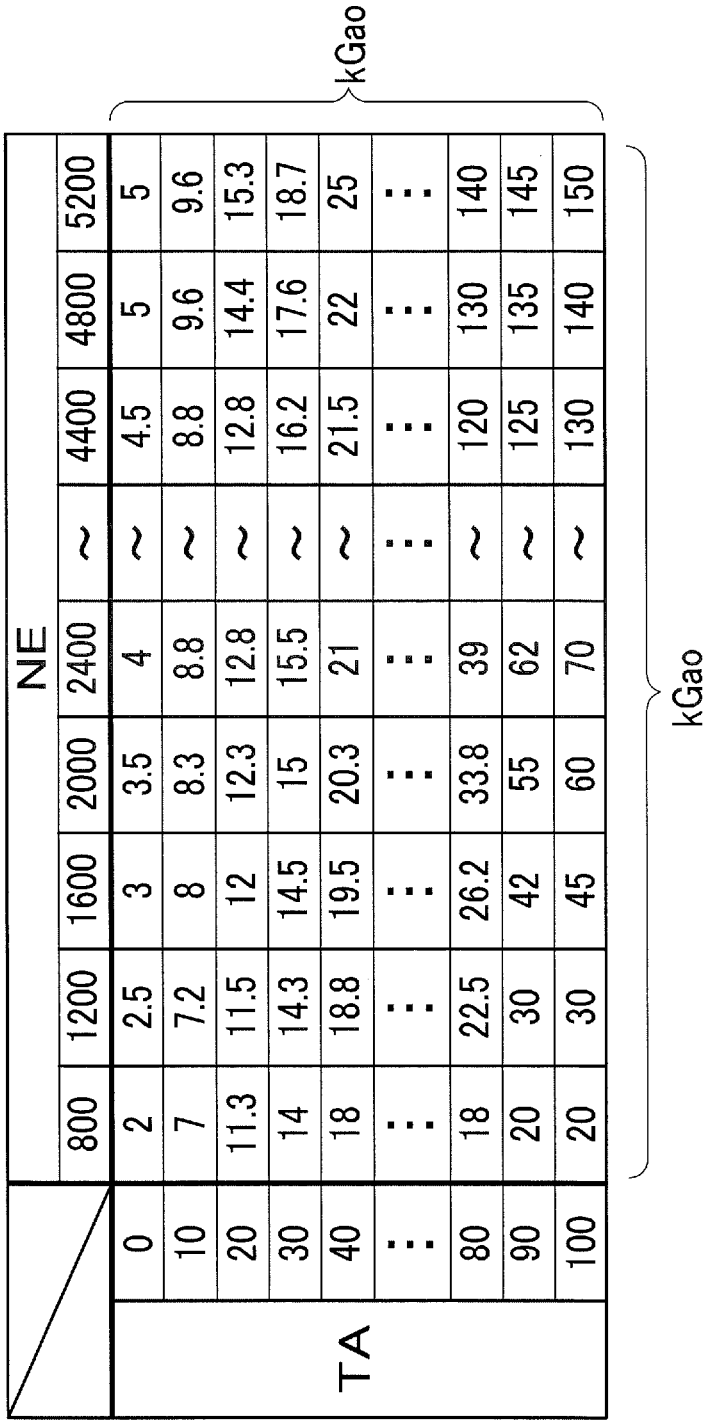

NE
TA
800
1200
1600
2000
2400
~
4400
4800
5200
0
10
20
30
40
80
90
100
2
7
11.3
14
18
18
20
20
2.5
7.2
11.5
14.3
18.8
22.5
30
30
3
8
12
14.5
19.5
26.2
42
45
3.5
8.3
12.3
15
20.3
33.8
55
60
4
8.8
12.8
15.5
21
39
62
70
4.5
8.8
12.8
16.2
21.5
120
125
130
5
9.6
15.3
18.7
25
140
145
150
kGao
kGao

FIG. 9

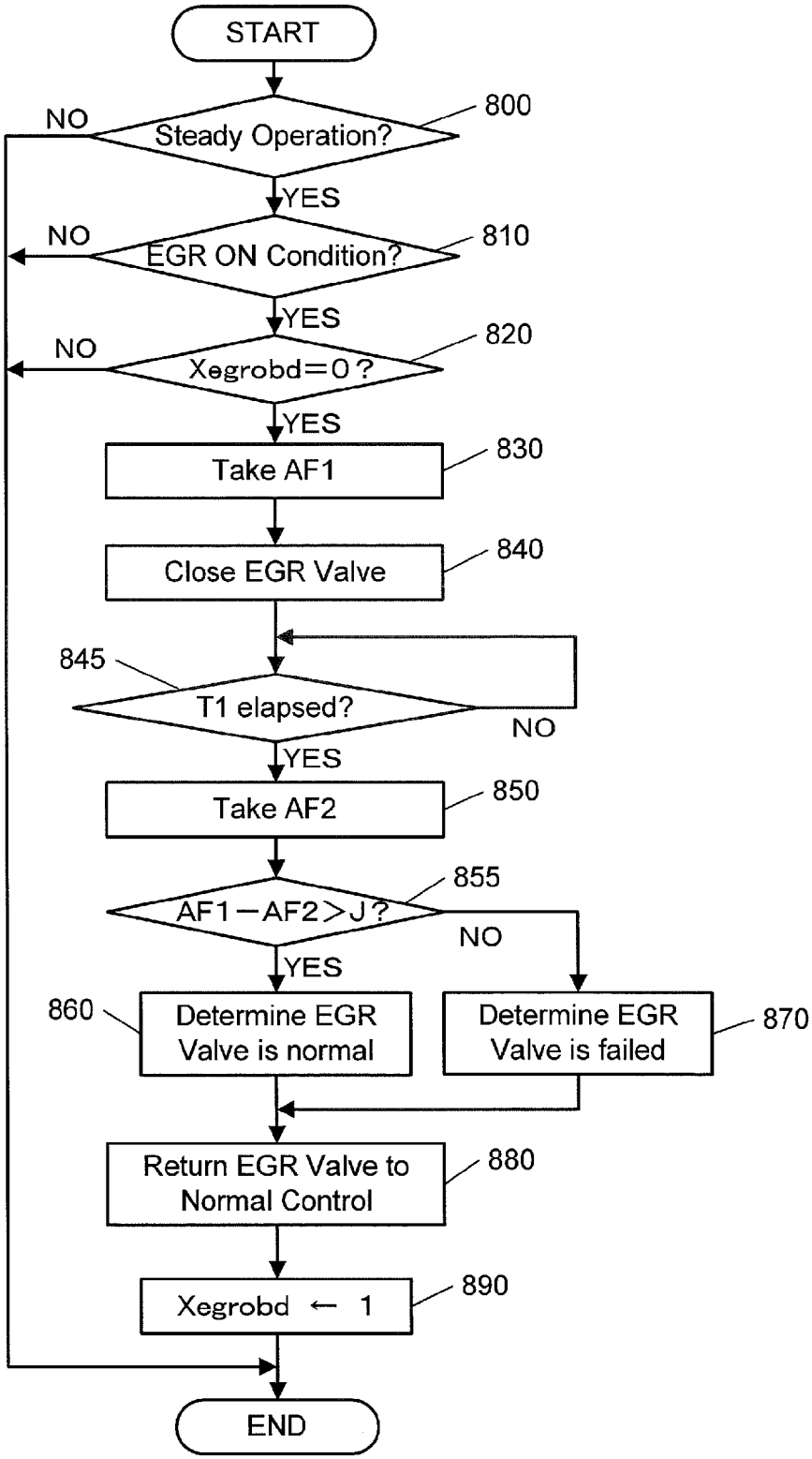

START
Steady Operation?
800
NO
YES
EGR ON Condition?
810
NO
YES
Xegrobd=0?
820
NO
YES
Take AF1
830
Close EGR Valve
840
845
T1 elapsed?
NO
YES
Take AF2
850
AF1−AF2>J?
855
NO
YES
860
Determine EGR Valve is normal
Determine EGR Valve is failed
870
Return EGR Valve to Normal Control
880
Xegrobd ← 1
890
END

FIG. 10

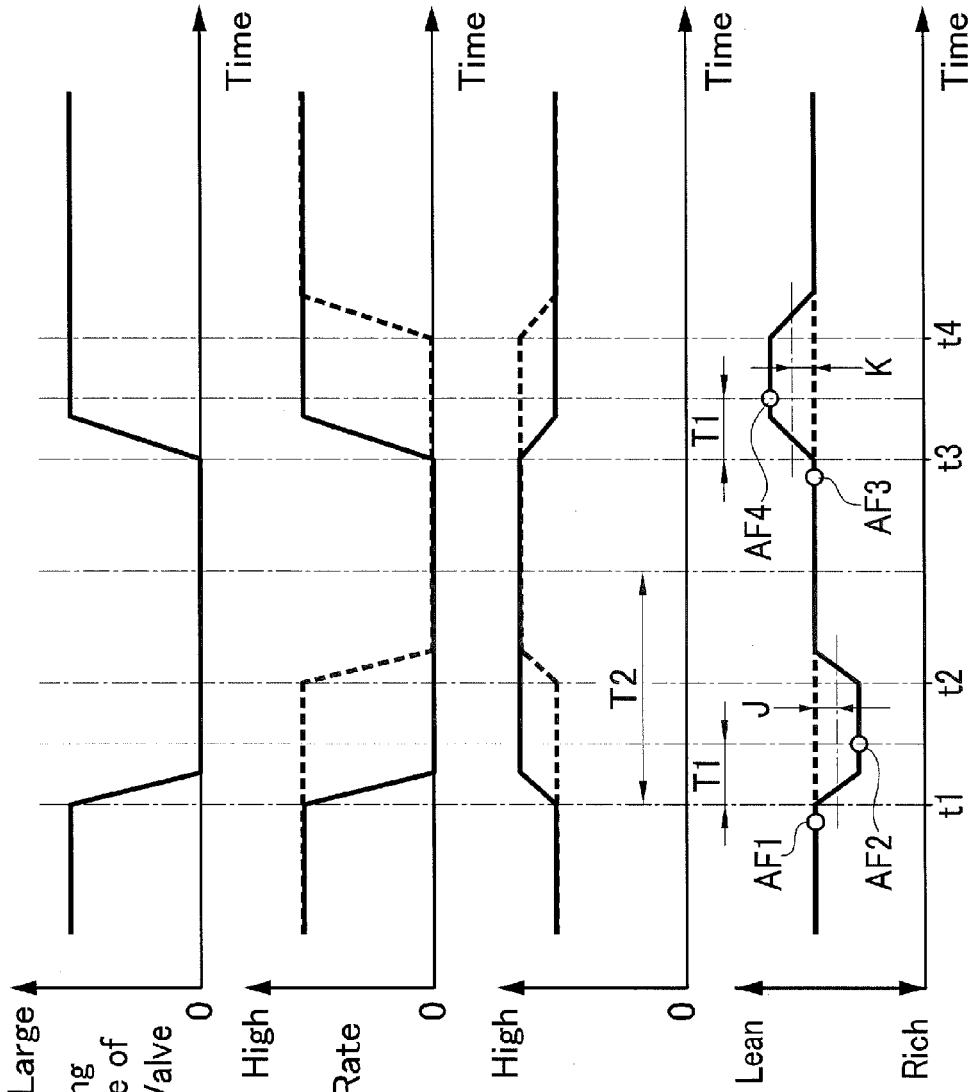

(a)
Large
Opening Degree of EGR Valve
0
Time
(b)
High
EGR Rate
0
Time
(c)
High
Ga
0
T2
Time
(d)
Lean
AF
Rich
T1
J
T1
K
AF1
AF2
AF3
AF4
t1
t2
t3
t4
Time

FIG. 11

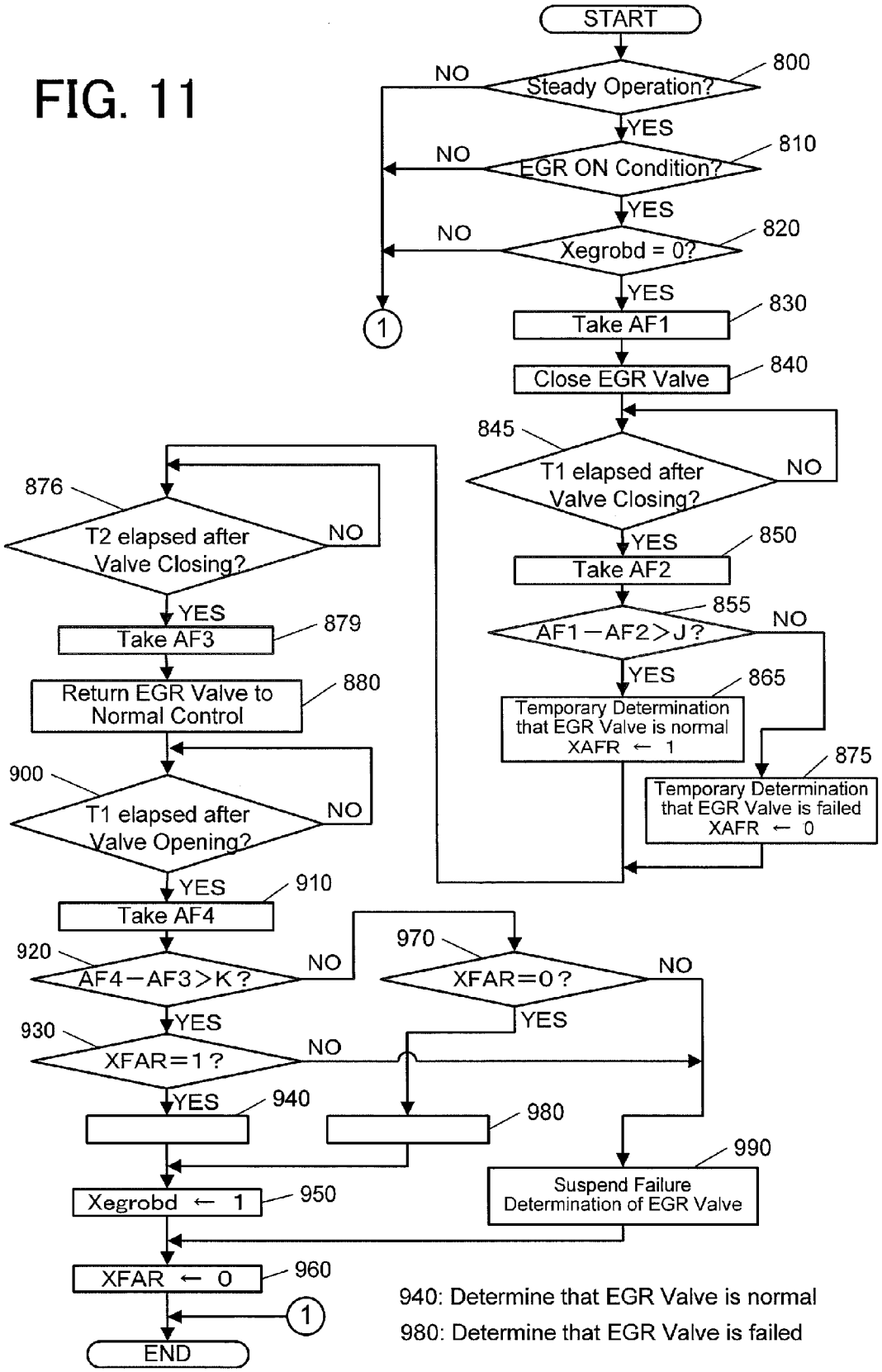
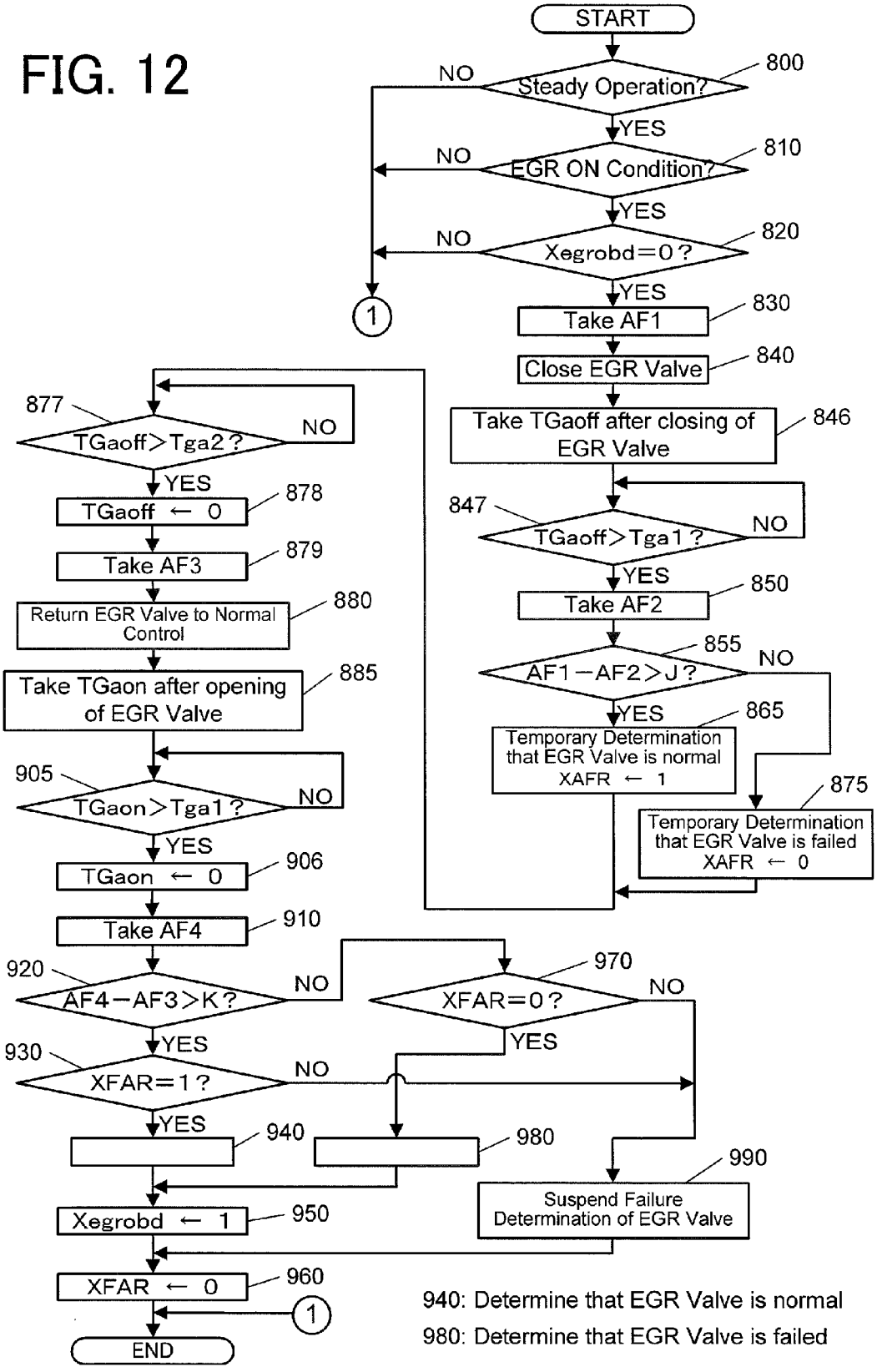

START
Steady Operation?
800
NO
YES
EGR ON Condition?
810
NO
YES
Xegrobd = 0?
820
NO
YES
1
Take AF1
830
Close EGR Valve
840
T1 elapsed after Valve Closing?
845
NO
YES
Take AF2
850
AF1−AF2>J?
855
NO
YES
Temporary Determination that EGR Valve is normal XAFR ← 1
865
Temporary Determination that EGR Valve is failed XAFR ← 0
875
T2 elapsed after Valve Closing?
876
NO
YES
Take AF3
879
Return EGR Valve to Normal Control
880
T1 elapsed after Valve Opening?
900
NO
YES
Take AF4
910
AF4−AF3>K?
920
NO
YES
XFAR=1?
930
NO
YES
XFAR=0?
970
NO
YES
940
980
Xegrobd ← 1
950
Suspend Failure Determination of EGR Valve
990
XFAR ← 0
960
1
END
940: Determine that EGR Valve is normal
980: Determine that EGR Valve is failed

FIG. 12



940: Determine that EGR Valve is normal

980: Determine that EGR Valve is failed

FIG. 13

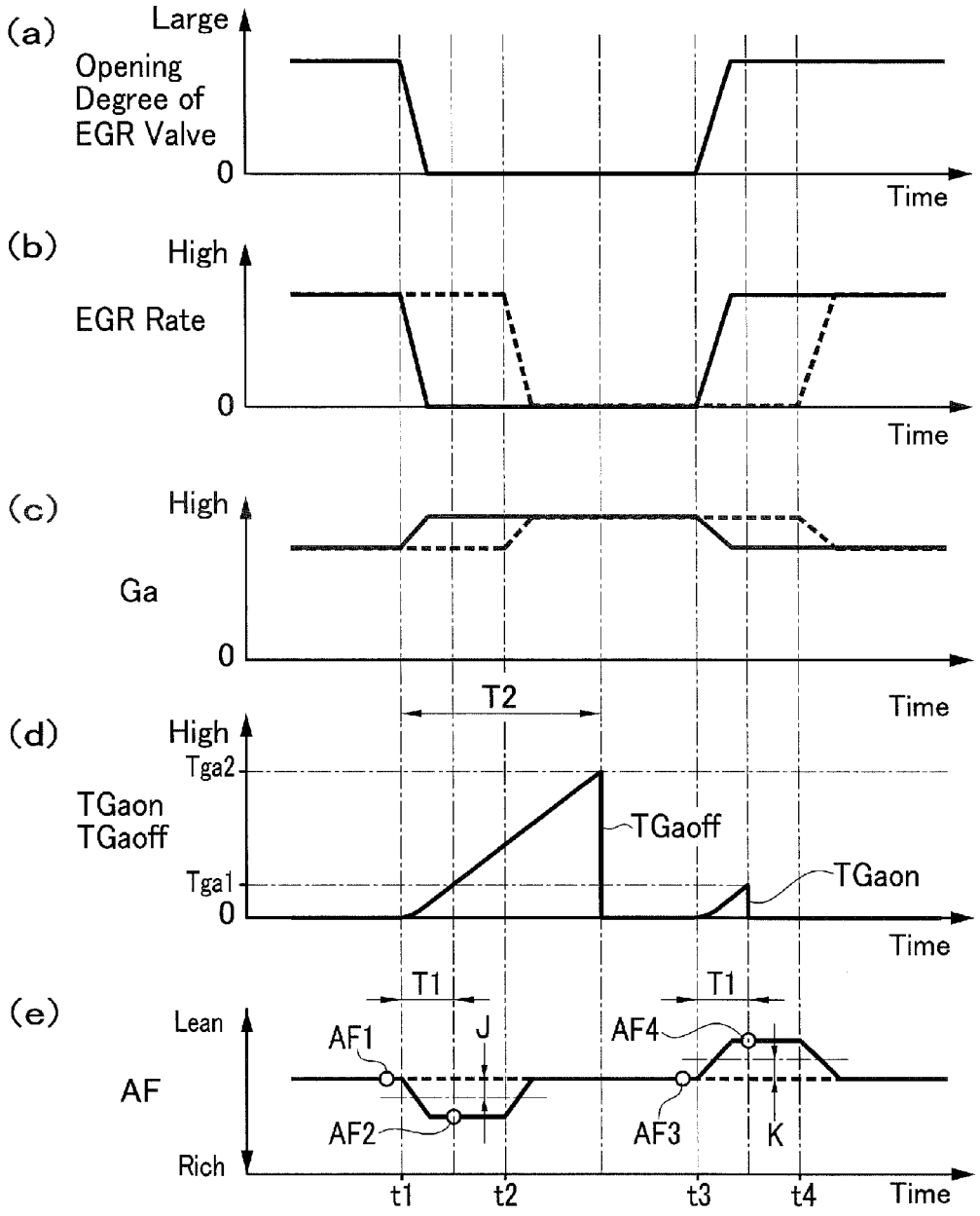
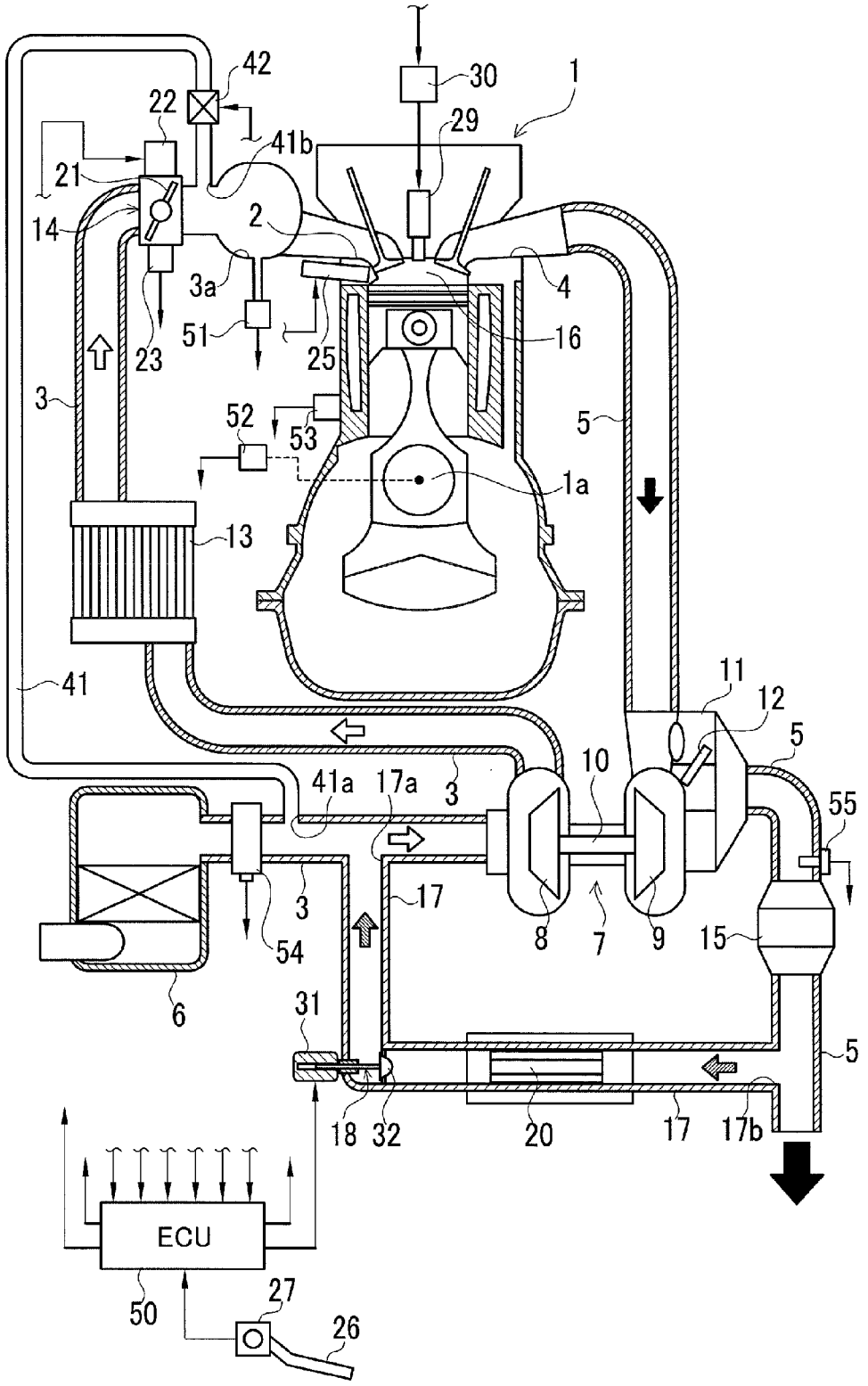

(a)
Large
Opening Degree of EGR Valve
0
Time
(b)
High
EGR Rate
0
Time
(c)
High
Ga
0
Time
T2
(d)
High
Tga2
TGaon
TGaoff
TGaoff
Tga1
TGaon
0
Time
T1
T1
(e)
Lean
AF1
J
AF4
AF
AF2
AF3
K
Rich
t1
t2
t3
t4
Time

FIG. 14



42
22
21
14
41b
2
3a
51
23
25
30
29
1
4
16
3
52
53
5
1a
13
41
11
12
5
10
41a
17a
3
55
3
17
54
8
7
9
15
6
31
5
18
32
20
17
17b
ECU
50
27
26

FIG. 15

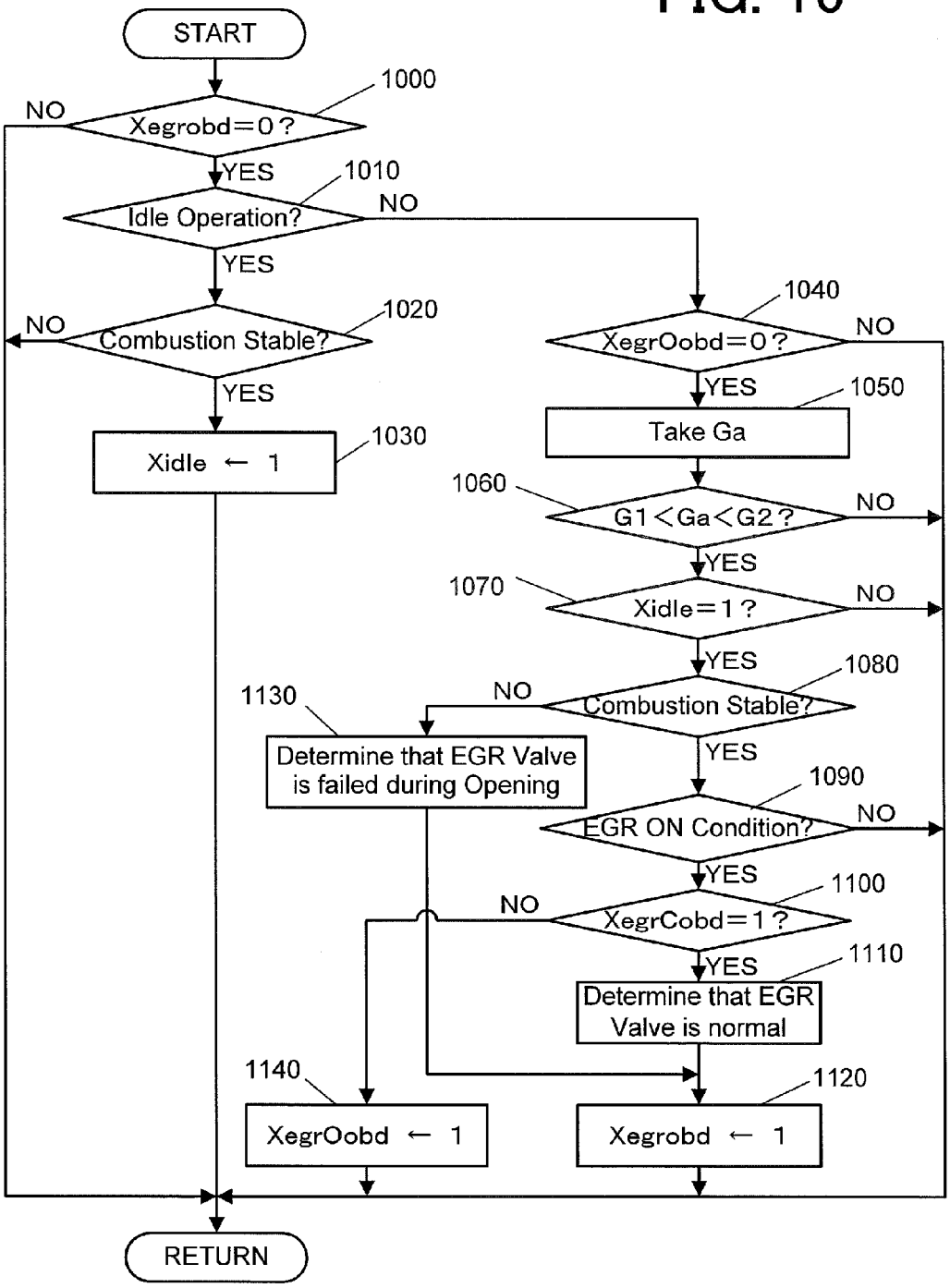

START
1000
Xegrobd=0?
NO
YES
1010
Idle Operation?
NO
YES
1020
Combustion Stable?
NO
YES
1030
Xidle ← 1
1040
XegrOobd=0?
NO
YES
1050
Take Ga
1060
G1<Ga<G2?
NO
YES
1070
Xidle=1?
NO
YES
1080
Combustion Stable?
NO
YES
1130
Determine that EGR Valve is failed during Opening
1090
EGR ON Condition?
NO
YES
1100
XegrCobd=1?
NO
YES
1110
Determine that EGR Valve is normal
1140
XegrOobd ← 1
1120
Xegrobd ← 1
RETURN

FIG. 16

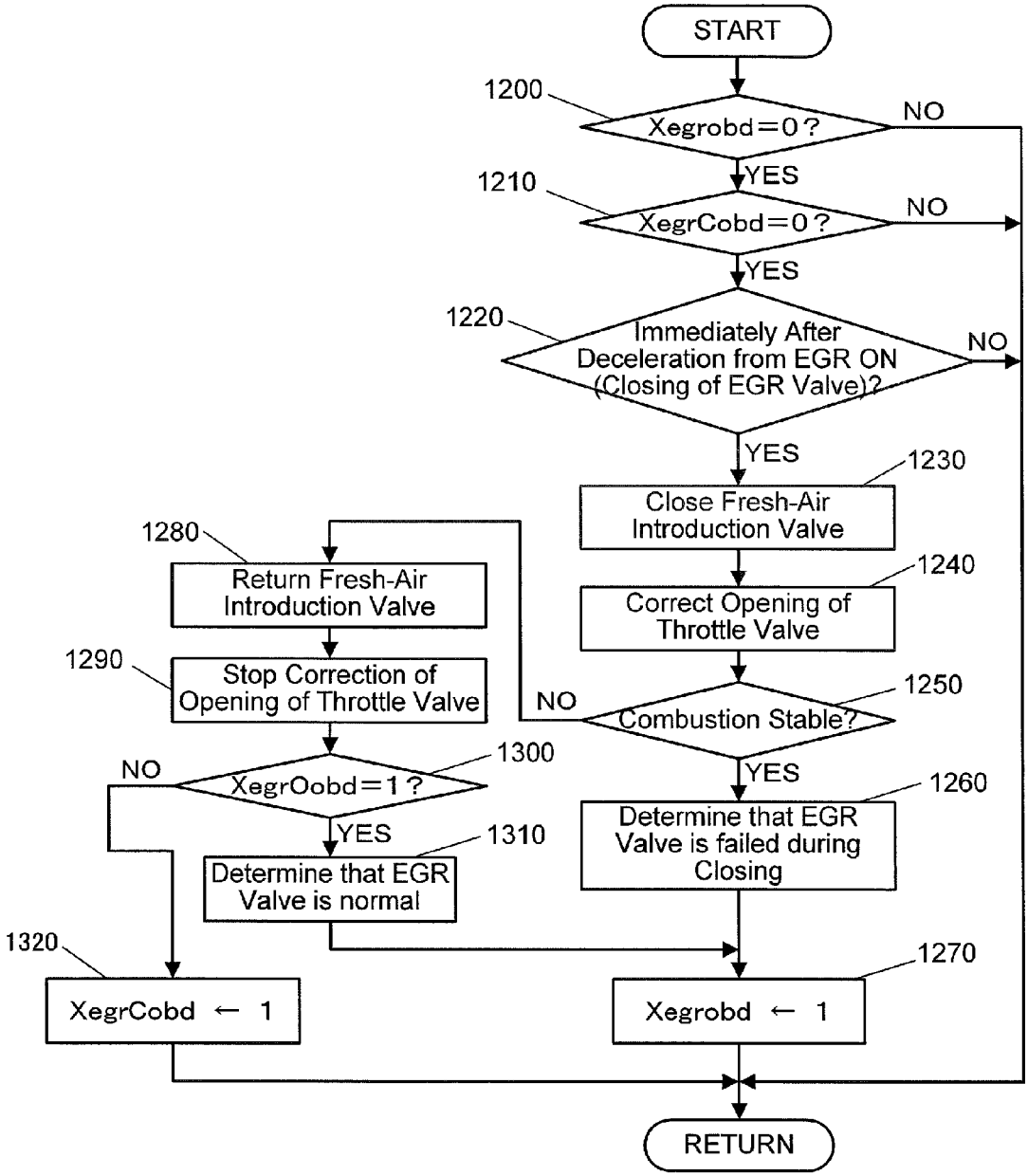
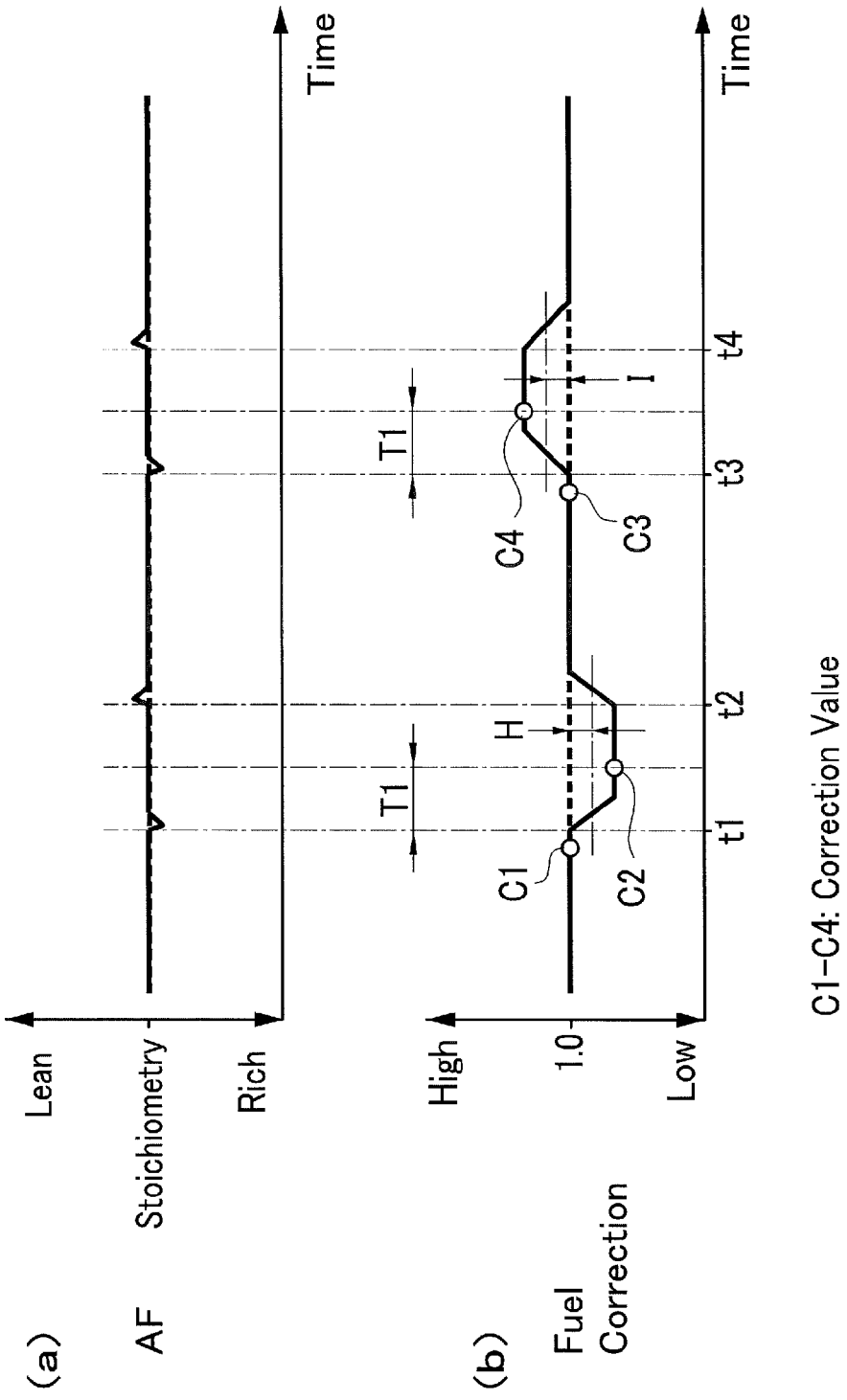

START
1200
Xegrobd=0?
NO
YES
1210
XegrCobd=0?
NO
YES
1220
Immediately After Deceleration from EGR ON (Closing of EGR Valve)?
NO
YES
1230
Close Fresh-Air Introduction Valve
1240
Correct Opening of Throttle Valve
1250
Combustion Stable?
NO
YES
1260
Determine that EGR Valve is failed during Closing
1270
Xegrobd ← 1
1280
Return Fresh-Air Introduction Valve
1290
Stop Correction of Opening of Throttle Valve
1300
XegrOobd=1?
NO
YES
1310
Determine that EGR Valve is normal
1320
XegrCobd ← 1
RETURN

FIG. 17


(a)
AF
Lean
Stoichiometry
Rich
Time
(b)
Fuel Correction
High
1.0
Low
Time
T1
T1
H
I
C1
C2
C3
C4
t1
t2
t3
t4
C1-C4: Correction Value

FAILURE DETECTION DEVICE FOR EXHAUST RECIRCULATION APPARATUS OF ENGINE WITH SUPERCHARGER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2013-142664 filed on Jul. 8, 2013, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an exhaust gas recirculation apparatus to allow part of exhaust gas discharged from an engine with a supercharger to an exhaust passage to flow as exhaust recirculation gas in an intake passage to return to the engine, and more particularly to a failure detection device configured to detect a failure of the exhaust recirculation apparatus.

2. Related Art

Conventionally, a technique of the above type is employed in a vehicle engine, for example. An exhaust gas recirculation (EGR) apparatus is arranged to introduce part of exhaust gas after combustion, which is discharged from a combustion chamber of an engine to an exhaust passage, into an intake passage as EGR gas through an EGR passage so that the exhaust gas is mixed with intake air flowing in the intake passage and returns to the combustion chamber. The EGR gas flowing in the EGR passage is regulated by an EGR valve provided in the EGR passage. This EGR can reduce mainly nitrogen oxide (NOx) in the exhaust gas and improve fuel consumption during a partial load operation of the engine.

Exhaust gas from the engine contains no oxygen or is in an oxygen lean state. Thus, when part of the exhaust gas is mixed with the intake air by EGR, the oxygen concentration of the intake air decreases. In a combustion chamber, therefore, fuel burns in a low oxygen concentration. Thus, a peak temperature during combustion decreases, thereby suppressing the occurrence of NOx. In a gasoline engine, even when the content of oxygen in intake air is not increased by EGR and a throttle valve is closed to some degree, it is possible to reduce pumping loss of the engine.

Herein, recently, it is conceivable to perform EGR in the entire operating region of the engine in order to further improve fuel consumption. Realization of high EGR rates is thus demanded. To realize the high EGR rates, it is necessary for conventional arts to increase the internal diameter of an EGR passage or increase the opening area of a flow passage provided by a valve element and a valve seat of an EGR valve.

Meanwhile, in case a failure occurs in an EGR apparatus, it may interfere with appropriate EGR control, leading to the occurrence of knocking in an engine or the deterioration in exhaust emission of the engine. Therefore, there is conventionally proposed a failure detection device configured to diagnose the presence/absence of a failure of the EGR apparatus, inform a driver of such a fact in case a failure is detected, and store the fact in a storage device.

JP-A-2011-252399 discloses a technique of the above type for failure detection. In this technique, an intake pressure sensor actually measures intake pressure in an intake passage when an EGR valve is controlled to open and close and also an expected intake pressure to be realized by the control to open and close the EGR valve is estimated. By comparison between an actual measured value and an estimated value of the intake pressure, it is determined whether or not a failure of the EGR apparatus is present. If the failure is determined to be present, the type of that failure is determined. Herein, if the actual measured value of the intake pressure is different from the estimated value, it means that the intake pressure did not vary even when the EGR valve was controlled to open and close. It is thus possible to determine that the EGR valve is failed.

Furthermore, it is well known to adopt an EGR apparatus of an engine with a supercharger. JP-A-2012-007547 describes an EGR apparatus adopted in an engine with a supercharger. This engine is provided with a supercharger consisting of a turbine placed in an exhaust passage and a compressor placed in an intake passage and driven by the turbine. In this EGR apparatus, an inlet of an EGR passage is connected to the exhaust passage downstream of the turbine and an outlet of the EGR passage is connected to the intake passage upstream of the compressor, whereby constituting a low pressure loop EGR apparatus.

SUMMARY OF INVENTION

Problems to be Solved by the Invention

Meanwhile, it is conceived that the low pressure loop EGR apparatus disclosed in JP-A-2012-007547 is also provided with a failure detection device. However, even if the low pressure loop EGR apparatus adopts the technique of failure detection disclosed in JP-A-2011-252399, the intake pressure does not vary only by controlling the EGR valve to open and close. Thus, it is impossible to determine whether or not the EGR apparatus is failed by comparison between an actual measured value and an estimated value of the intake pressure.

In the low pressure loop EGR apparatus, therefore, it is conceivable to use a temperature sensor instead of the intake pressure sensor to detect a failure of the EGR apparatus. Specifically, the temperature sensor is placed in the intake passage downstream of the outlet of the EGR passage to actually measure the temperature of gas flowing in the intake passage when the EGR valve is controlled to open and close to thereby determine whether or not EGR gas has flowed in the intake passage. This can determine whether or not the EGR valve is normally operated to open and close, that is, whether or not the EGR apparatus is normal. In this case, however, the temperature sensor for failure detection has to be additionally provided, resulting in a cost increase of the EGR apparatus by just that much.

The present invention has been made in view of the circumstances and has a purpose to provide a failure detection device for an exhaust recirculation apparatus of an engine with a supercharger, the failure detection device being configured to enable effective detection of a failure of an exhaust recirculation valve without separately providing any additional unit or means for failure detection in a low pressure loop exhaust recirculation apparatus.

Means of Solving the Problems

To achieve the above purpose, one aspect of the invention provides a failure detection device for an exhaust recirculation apparatus of an engine with a supercharger, the engine including an intake passage, an exhaust passage, and a fuel supply unit to supply fuel to a combustion chamber, the intake passage being provided with an intake regulating

valve to regulate an intake amount flowing in the intake passage, the supercharger including a compressor placed in the intake passage upstream of the intake regulating valve, a turbine placed in the exhaust passage, and a rotary shaft connecting the compressor and the turbine so that they are integrally rotatable, the exhaust recirculation apparatus including: an exhaust recirculation passage to allow part of exhaust gas discharged from the combustion chamber of the engine to the exhaust passage to flow as exhaust recirculation gas to the intake passage to return to the combustion chamber; and an exhaust recirculation valve to regulate a flow of the exhaust recirculation gas in the exhaust recirculation passage, and the exhaust recirculation passage having an inlet connected to the exhaust passage downstream of the turbine and an outlet connected to the intake passage upstream of the compressor, wherein the failure detection device includes a failure determining unit configured to control the exhaust recirculation valve while the engine is in a predetermined operating condition and further determine whether or not the exhaust recirculation valve is failed based on changes in intake amount in the intake passage caused by the exhaust recirculation valve under control.

Another aspect of the invention provides a failure detection device for an exhaust recirculation apparatus of an engine with a supercharger, the engine including an intake passage, an exhaust passage, and a fuel supply unit to supply fuel to a combustion chamber, the intake passage being provided with an intake regulating valve to regulate an intake amount flowing in the intake passage, the supercharger including a compressor placed in the intake passage upstream of the intake regulating valve, a turbine placed in the exhaust passage, and a rotary shaft connecting the compressor and the turbine so that they are integrally rotatable, the exhaust recirculation apparatus including: an exhaust recirculation passage to allow part of exhaust gas discharged from the combustion chamber of the engine to the exhaust passage to flow as exhaust recirculation gas to the intake passage to return to the combustion chamber; and an exhaust recirculation valve to regulate a flow of the exhaust recirculation gas in the exhaust recirculation passage, and the exhaust recirculation passage having an inlet connected to the exhaust passage downstream of the turbine and an outlet connected to the intake passage upstream of the compressor, wherein the failure detection device includes a failure determining unit configured to determine whether or not the exhaust recirculation valve is failed based on changes in combustion state of the fuel in the combustion chamber supplied by the fuel supply unit while the engine is in a predetermined operating condition.

Advantageous Effects of Invention

According to the present invention, it is possible to effectively detect a failure in an exhaust recirculation valve without separately providing any additional unit or means for failure detection in a low pressure loop exhaust recirculation apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic configuration view showing an engine system including an EGR apparatus of an engine with a supercharger in a first embodiment;

FIG. **2** is an enlarged cross sectional view of a part of an EGR passage, in which an EGR valve is provided in the first embodiment;

FIG. **3** is a flowchart showing one example of processing details to detect a failure of the EGR valve in the first embodiment;

FIG. **4** is an estimated intake amount map to be referred to in order to find an estimated intake amount during valve closing of the EGR valve in the first embodiment;

FIG. **5** is a flowchart showing one example of processing details to detect a failure in an EGR valve in a second embodiment;

FIG. **6** is a flowchart showing one example of processing details to detect a failure in a EGR valve in a third embodiment;

FIG. **7** is a flowchart showing one example of processing details to detect a failure in a EGR valve in a fourth embodiment;

FIG. **8** is an estimated intake amount map to be referred to in order to find an estimated intake amount during valve opening of the EGR valve in the fourth embodiment;

FIG. **9** is a flowchart showing one example of processing details to detect a failure in a EGR valve in a fifth embodiment;

FIG. **10** is a time chart showing behaviors of (a) opening degree of the EGR valve, (b) EGR rate, (c) intake amount, and (d) air-fuel ratio when the EGR valve is normal in the fifth embodiment;

FIG. **11** is a flowchart showing one example of processing details to detect a failure in a EGR valve in a sixth embodiment;

FIG. **12** is a flowchart showing one example of processing details to detect a failure in a EGR valve in a seventh embodiment;

FIG. **13** is a time chart showing behaviors of (a) opening degree of the EGR valve, (b) EGR rate, (c) intake amount, (d) accumulated intake amounts after valve closing and after valve opening of the EGR valve, and (e) air-fuel ratio when the EGR valve is normal in the seventh embodiment;

FIG. **14** is a schematic configuration view showing an engine system including an EGR apparatus of an engine with a supercharger in an eighth embodiment;

FIG. **15** is a flowchart showing one example of processing details to detect a failure in an EGR valve in the eighth embodiment;

FIG. **16** is a flowchart showing one example of processing details to detect a failure in a EGR valve in the eighth embodiment; and

FIG. **17** is a time chart showing behaviors of (a) air-fuel ratio and (b) fuel correction when a EGR valve is normal in another embodiment.

DESCRIPTION OF EMBODIMENTS

<First Embodiment>

A detailed description of a first embodiment of a failure detection device for an exhaust gas recirculation apparatus of an engine with a supercharger (a supercharger-equipped engine) embodying the present invention will now be given referring to the accompanying drawings.

FIG. **1** is a schematic configuration view showing an engine system including an exhaust gas recirculation (EGR) apparatus of a supercharger-equipped engine in the present embodiment. This engine system includes a reciprocating-type engine **1**. This engine **1** has an intake port **2** connected to an intake passage **3** and an exhaust port **4** connected to an exhaust passage **5**. An air cleaner **6** is provided at an inlet of the intake passage **3**. In the intake passage **3** downstream of the air cleaner **6**, a supercharger **7** is placed in a position

between a portion of the intake passage **3** and a portion of the exhaust passage **5** to increase the pressure of intake air in the intake passage **3**.

The supercharger **7** includes a compressor **8** placed in the intake passage **3**, a turbine **9** placed in the exhaust passage **5**, and a rotary shaft **10** connecting the compressor **8** and the turbine **9** so that they are integrally rotatable. The supercharger **7** is configured to rotate the turbine **9** with exhaust gas flowing in the exhaust passage **5** and integrally rotate the compressor **8** through the rotary shaft **10** in order to increase the pressure of intake air in the intake passage **3**, that is, carry out supercharging.

In the exhaust passage **5**, adjacent to the supercharger **7**, an exhaust bypass passage **11** is provided by detouring around the turbine **9**. In this exhaust bypass passage **11**, a waste gate valve **12** is placed. This waste gate valve **12** regulates exhaust gas allowed to flow in the exhaust bypass passage **11**. Thus, a flow rate of exhaust gas to be supplied to the turbine **9** is regulated, thereby controlling the rotary speeds of the turbine **9** and the compressor **8**, and adjusting supercharging pressure of the supercharger **7**.

In the intake passage **3**, an intercooler **13** is provided between the compressor **8** of the supercharger **7** and the engine **1**. This intercooler **13** serves to cool intake air having the pressure increased by the compressor **8** and hence a high temperature, down to an appropriate temperature. A surge tank **3***a* is provided in the intake passage **3** between the intercooler **13** and the engine **1**. Further, an electronic throttle device **14** that is an electrically-operated throttle valve is placed downstream of the intercooler **13** but upstream of the surge tank **3***a*. This throttle device **14** corresponding to one example of an intake regulating valve of the invention includes a butterfly-shaped throttle valve **21** placed in the intake passage **3**, a step motor **22** to drive the throttle valve **21** to open and close, and a throttle sensor **23** to detect an opening degree or position (a throttle opening degree) TA of the throttle valve **21**. The throttle sensor **23** corresponds to one example of an opening degree detecting unit of the present invention. The throttle device **14** is configured so that the throttle valve **21** is driven by the step motor **22** to open and close according to operation of an accelerator pedal **26** by a driver to adjust the opening degree of the throttle valve **21**. The configuration of this throttle device **14** can be provided by for example a basic configuration of a "throttle device" disclosed in JP-A-2011-252482, FIGS. 1 and 2. In the exhaust passage **5** downstream of the turbine **9**, a catalytic converter **15** is provided as an exhaust catalyst to clean exhaust gas.

The engine **1** is further provided with an injector(s) **25** to inject and supply fuel into a combustion chamber(s) **16**. The injector **25** is configured to be supplied with the fuel from a fuel tank (not shown). The engine **1** is further provided with an ignition plug **29** in each cylinder. Each of the ignition plugs **29** ignites in response to high voltage output from an igniter **30**. An ignition timing of each ignition plug **29** is determined by output timing of the high voltage from the igniter **30**. The ignition plugs **29** and the igniter **30** constitute an ignition device.

In the present embodiment, the EGR apparatus to enable high EGR rates is a low pressure loop system and includes an exhaust gas recirculation (EGR) passage **17** allowing part of exhaust gas discharged from the combustion chamber **16** of the engine **1** to the exhaust passage **5** to flow in the intake passage **3** and return to the combustion chamber **16**, and an exhaust gas recirculation (EGR) valve **18** placed in the EGR passage **17** to regulate an exhaust gas flow rate (EGR flow rate) in the EGR passage **17**. The EGR passage **17** is provided to extend between the exhaust passage **5** downstream of the catalytic converter **15** and the intake passage **3** upstream of the compressor **8**. Specifically, an outlet **17***a* of the EGR passage **17** is connected to the intake passage **3** upstream of the compressor **8** in order to allow a part of exhaust gas flowing in the exhaust passage **5** to flow as EGR gas into the intake passage **3** and return to the combustion chamber **16**. An inlet **17***b* of the EGR passage **17** is connected to the exhaust passage **5** downstream of the catalytic convertor **15**.

In the EGR passage **17**, an EGR cooler **20** is provided to cool EGR gas flowing in the EGR passage **17**. In the present embodiment, the EGR valve **18** is located in the EGR passage **17** downstream of the EGR cooler **20**.

FIG. **2** is an enlarged cross sectional view of a part of the EGR passage **17** in which the EGR valve **18** is provided. As shown in FIGS. **1** and **2**, the EGR valve **18** is configured as a poppet valve and a motor-operated valve. Specifically, the EGR valve **18** is provided with a valve element **32** to be driven by a DC motor **31**. The valve element **32** has an almost conical shape and is configured to seat on a valve seat **33** provided in the EGR passage **17**. The DC motor **31** includes an output shaft **34** arranged to reciprocate in a straight line (stroke movement). The valve element **32** is fixed at a leading end of the output shaft **34**. This output shaft **34** is supported in a housing defining the EGR passage **17** through a bearing **35**. The stroke movement of the output shaft **34** of the DC motor **31** is performed to adjust the opening degree of the valve element **32** with respect to the valve seat **33**. The output shaft **34** of the EGR valve **18** is provided to be able to make stroke movement by a predetermined stroke L**1** between a fully closed position in which the valve element **32** seats on the valve seat **33** and a fully opened position in which the valve element **32** contacts with the bearing **35**. In the present embodiment, an opening area of the valve seat **33** is set larger than a conventional one in order to achieve high EGR rates. Accordingly, the valve element **32** is also designed with large size. As the structure of the above EGR valve **18**, for example, a basic structure of an "EGR valve" disclosed in FIG. 1 of JP-A-2010-275941 can be adopted.

In the present embodiment, for respectively executing fuel injection control, ignition timing control, intake amount control, EGR control, and other controls according to the operating condition of the engine **1**, an electronic control unit (ECU) **50** controls the injectors **25**, the igniter **30**, the step motor **22** of the electronic throttle device **14**, and the DC motor **31** of the EGR valve **18** according to the operating condition of the engine **1**. The ECU **50** includes a central processing unit (CPU), various memories that store a predetermined control program and others in advance and that temporarily store computational results and others of the CPU, and an external input circuit and an external output circuit connected to each of them. The ECU **50** is one example of a failure determining unit of the invention. To the external output circuit, there are connected the igniter **30**, the injectors **25**, the step motor **22**, and the DC motor **31**. To the external input circuit, there are connected the throttle sensor **23** and various sensors **27** and **51**-**55** which correspond to one example of an operating condition detecting unit to detect the operating condition of the engine **1** and transmit various engine signals to the external input circuit.

In the present embodiment, the various sensors include the accelerator sensor **27**, the intake pressure sensor **51**, the rotation speed sensor **52**, the water temperature sensor **53**, the air flow meter **54**, and the air-fuel ratio sensor **55** as well as the throttle sensor **23**. The accelerator sensor **27** detects an

accelerator opening degree ACC which is an operation amount of the accelerator pedal **26**. This accelerator pedal **26** corresponds to one example of an operating unit to control the operation of the engine **1**. The intake pressure sensor **51** detects intake pressure PM in the surge tank **3***a*. That is, the intake pressure sensor **51** is configured to detect intake pressure PM in the intake passage **3** (the surge tank **3***a*) downstream of a position in which EGR gas flows in the intake passage **3** from the EGR passage **17**. The rotation speed sensor **52** detects the rotation angle (crank angle) of the crank shaft **1***a* of the engine **1** and also detects changes in crank angle as the rotation speed (engine rotation speed) NE of the engine **1**. The rotation speed sensor **52** corresponds to one example of a rotation detecting unit and a combustion state detecting unit of the invention. The water temperature sensor **53** detects the cooling water temperature THW of the engine **1**. The air flow meter **54** detects a flow amount Ga of intake air flowing in the intake passage **3** directly downstream of the air cleaner **6**. The air flow meter **54** corresponds to one example of an intake amount measuring unit of the invention. The air-fuel ratio sensor **55** is placed in the exhaust passage **5** directly upstream of the catalytic convertor **15** to detect an air-fuel ratio AF in the exhaust gas. This sensor **55** corresponds to one example of an air-fuel ratio detecting unit of the invention.

In the present embodiment, the ECU **50** is configured to control the EGR valve **18** in the whole operating region of the engine **1** to control EGR according to the operating condition of the engine **1**. On the other hand, the ECU **50** is arranged to normally control the EGR valve **18** to open based on an operating condition detected during acceleration operation or steady operation of the engine **1** and control the EGR valve **18** to close during stop of the engine **1**, during idle operation, or during deceleration operation.

In the present embodiment, the ECU **50** is arranged to control the electronic throttle device **14** based on an accelerator opening degree ACC in order to drive the engine **1** in response to requests from a driver. The ECU **50** is further arranged to control the electronic throttle device **14** to open based on the accelerator opening degree ACC during acceleration operation or steady operation of the engine **1** and to control the electronic throttle device **14** to close during stop or deceleration operation of the engine **1**. Accordingly, the throttle valve **21** is opened during acceleration operation or steady operation of the engine **1** and closed during stop or deceleration operation of the engine **1**.

Herein, even the low pressure loop EGR apparatus of the present embodiment needs to perform effective failure detection for executing appropriate EGR control. In this embodiment, therefore, the ECU **50** executes the following processings in order to detect a failure of the low pressure loop EGR apparatus without separately providing any additional unit or means for failure detection.

FIG. **3** is a flowchart showing one example of details of the processing to detect a failure of the EGR valve **18**. When the processing proceeds to this routine, the ECU **50** firstly determines in Step **100** whether or not the operating condition of the engine **1** is a deceleration fuel cutoff condition. That is, it is determined whether or not the engine **1** is in a deceleration operation and fuel supply to the engine **1** by the injectors **25** is cut off. This condition is referred to as "deceleration fuel cutoff". During the deceleration operation of the engine **1**, as described above, the throttle valve **21** of the electronic throttle device **14** is controlled to fully close. The ECU **50** can make the above determination based on changes in accelerator opening degree ACC. If a negative determination (NO) is made in this Step **100**, the ECU **50** immediately terminates the processing. If a positive determination (YES) is made in Step **100**, the ECU **50** shifts the processing to Step **110**.

In Step **110**, the ECU **50** determines whether or not a failure determination flag Xegrobd is "0". Herein, the failure determination flag Xegrobd is set to "1" when the failure determination was performed, but set to "0" when the failure determination was not performed. If NO in Step **110**, the ECU **50** immediately terminates the processing. If YES in Step **110**, the ECU **50** advances the processing to Step **120**.

In Step **120**, the ECU **50** judges whether or not a valve-closing flag Xegrclose is "0". This valve-closing flag Xegrclose is set to "1" when the EGR valve **18** is being controlled to close, but set to "0" when the EGR valve **18** is not controlled to close. If NO in Step **120**, the ECU **50** shifts the processing to Step **190**. If YES in Step **120**, on the other hand, the ECU **50** shifts the processing to Step **130**.

In Step **130**, the ECU **50** controls the EGR valve **18** to close. Thus, the EGR valve **18** remaining in a valve-open state is forcibly closed. Then, the EGR valve **18** is held in a valve-closed state.

In Step **140**, successively, the ECU **50** takes, or reads, the engine rotation speed NE based on a detection value of the rotation speed sensor **52** and further takes the throttle opening degree TA based on a detection value of the throttle sensor **23**.

In Step **150**, the ECU **50** finds an estimated intake amount kGac during valve closing of the EGR valve **18** based on the engine rotation speed NE and the throttle opening degree TA. The ECU **50** can find this estimated intake amount kGac by referring to for example an estimated intake amount map shown in FIG. **4**. In this map, the estimated intake amount kGac is set to be larger as the engine rotation speed NE is higher and the throttle opening degree TA is larger.

In Step **160**, the ECU **50** then takes an intake amount Ga based on a measurement value of the air flow meter **54**. In Step **170**, the ECU **50** sets the taken intake amount Ga as an intake amount Gac during valve closing ("valve-closing intake amount Gac") obtained when the EGR valve **18** is closed.

In Step **180**, the ECU **50** sets the valve closing flag Xegrclose to "1" and returns the processing to Step **120**.

On the other hand, in Step **190** subsequent to Step **120**, the ECU **50** controls to open the EGR valve **18** having been controlled to close. Thus, the EGR valve **18** in a valve-closed state is forcibly opened.

In Step **200**, the ECU **50** takes an intake amount Ga based on a measurement value of the air flow meter **54**. In Step **210**, the ECU **50** successively sets the taken intake amount Ga as an intake amount Gao during valve opening ("valve-opening intake amount Gao") obtained when the EGR valve **18** is opened.

Subsequently, in Step **220**, the ECU **50** determines whether or not an absolute value of a difference between the valve-closing intake amount Gac and the valve-opening intake amount Gao is smaller than a predetermined value A. Specifically, the ECU **50** determines whether or not the difference between the intake amount Ga actually measured when the EGR valve **18** is controlled to close and the intake amount Ga actually measured when the EGR valve **18** is controlled to open is smaller than the predetermined value A. If No in Step **220**, the ECU **50** shifts the processing to Step **270**. If YES in Step **220**, the ECU **50** shifts the processing to Step **230**.

In Step **270**, since the difference between the valve-closing intake amount Gac and the valve-opening intake amount Gao is large, the ECU **50** determines the EGR valve

18 is normal, that is, the EGR valve 18 is functioning normally, and advances the processing to Step 250. At that time, the ECU 50 can store, in a memory, the fact that the EGR valve 18 is determined to be normal ("normality determination").

In Step 230, on the other hand, the ECU 50 determines whether or not an absolute value of a difference between the estimated intake amount kGac during valve closing and the valve-closing intake amount Gac is smaller than a predetermined value B. Specifically, the ECU 50 determines whether or not the difference between the estimated intake amount kGac and the actual measured intake amount Gac is smaller than the predetermined value B when the EGR valve 18 is controlled to close. If YES in Step 230, it is considered that the EGR valve 18 remains closed, the ECU 50 then determines in Step 240 that the EGR valve 18 is failed, that is, the EGR valve 18 is malfunctioning, in a closed state ("closed-valve failure determination") and shifts the processing to Step 250. At that time, the ECU 50 can notify a driver of the fact that the of closed-valve failure determination or store this fact in a memory.

If NO in Step 230, on the other hand, it is considered that the EGR valve 18 remains open, the ECU 50 determines that the EGR valve 18 is failed in the valve-open state ("open-valve failure determination") and shifts the processing to Step 250. At that time, the ECU 50 can notify a driver of the fact of open-valve failure determination or store this fact in a memory.

In Step 250 subsequent to Step 270, 240, or 260, the ECU 50 sets the failure determination flag Xegrobd to "1" and terminates the processing.

According to the above control, while the engine 1 is in a predetermined operating condition, the ECU 50 determines if the EGR valve 18 is failed based on changes in intake amount Ga in the intake passage 3 obtained when the EGR valve 18 is controlled. More specifically, while the engine 1 is in a deceleration operation and when fuel supply to the engine 1 by the injectors 25 is cut off, the ECU 50 forcibly closes the EGR valve 18 and then forcibly opens the same and determines if the EGR valve 18 is failed based on changes in intake amount Ga measured by the air flow meter 54.

According to the above control, furthermore, when the EGR valve 18 is determined failed, the ECU 50 finds the estimated intake amount kGac during valve closing of the EGR valve 18 based on the engine rotation speed NE and the throttle opening degree TA and also finds an actual measured value of the intake amount Ga by the air flow meter 54. The ECU 50 then compares the estimated intake amount kGac and the actual measured, valve-closing intake amount Gac to further determine whether the EGR valve 18 remaining open is failed ("open-valve failure") or the EGR valve 18 remaining closed is failed ("closed-valve failure").

According to the failure detection device of the present embodiment explained above, when the normal EGR valve 18 is controlled while the engine 1 is in a predetermined operating condition, a flow of EGR gas from the EGR passage 17 to the intake passage 3 changes, thereby changing the intake amount Ga flowing in the intake passage 3. Herein, in case the EGR valve 18 is failed, an estimated change in flow of EGR gas does not appear even when the EGR valve 18 is controlled. Thus, the intake amount Ga flowing in the intake passage 3 does not change as estimated. Accordingly, while the engine 1 is in a predetermined operating condition, when the ECU 50 controls the EGR valve 18 and determines the presence/absence of changes in intake amount Ga in the intake passage 3 at that time, the presence/absence of a failure of the EGR valve 18 is determined. To be more specific, during the deceleration operation of the engine 1 and when fuel supply to the engine 1 by the injectors 25 is cut off, that is, during deceleration fuel cutoff, the ECU 50 forcibly opens and closes the EGR valve 18 and determines whether or not the intake amount Ga measured by the air flow meter 54 changes, thereby determining the presence/absence of a failure of the EGR valve 18. Herein, the air flow meter 54 is used to detect the intake amount Ga representing the operating condition of the engine 1. Thus, there is no need to provide any additional unit or means for detecting a failure of the EGR valve 18. Consequently, during deceleration fuel cutoff of the engine 1, it is possible to effectively detect a failure of the EGR valve 18 without providing any additional unit or means for failure detection in the low pressure loop EGR apparatus.

According to the present embodiment, when the ECU 50 determines that the EGR valve 18 is failed, the ECU 50 finds the estimated intake amount kGac during valve closing of the EGR valve 18 based on the engine rotation speed NE and the throttle opening degree TA and also finds the actual measured value of the intake amount Ga. By comparing the estimated intake amount kGac and the intake amount Ga, the ECU 50 further determines whether the EGR valve 18 is in open-valve failure or closed-valve failure. This can further specify whether the EGR valve 18 is in open-valve failure or closed-valve failure.

<Second Embodiment>

A second embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the invention will be explained in detail below referring to the accompanying drawings.

Like components or parts in each of the following embodiments to those in the first embodiment are assigned the same reference signs as those in the first embodiment and their details are not repeatedly explained below. The following embodiments will be therefore explained with a focus on differences from the first embodiment.

The second embodiment differs from the first embodiment in the processing details of failure detection. FIG. 5 is a flowchart showing one example of the processing details for detecting a failure of the EGR valve 18 in the present embodiment. The flowchart of FIG. 5 is different from the flowchart of FIG. 3 in additionally including the processing of Step 135.

Specifically, the ECU 50 controls the EGR valve 18 to close in Step 130 and then controls the throttle valve 21 to open by a predetermined opening degree C. in Step 135. For this purpose, the ECU 50 controls the electronic throttle device 14. Herein, the predetermined opening degree C. can be set, as one example, to "10%" on the assumption that full open of the opening degree is "100%".

According to the above control, different from the first embodiment, during deceleration fuel cutoff of the engine 1, the ECU 50 forcibly closes the EGR valve 18 from a valve open state and also opens the throttle valve 21 to the predetermined opening degree C. and then determines whether or not the EGR valve 18 is failed based on changes in intake amount Ga measured by the air flow meter 54.

According to the failure detection device of the present embodiment explained above, the following operations and effects can be provided as well as the operations and effects in the first embodiment. In the present embodiment, specifically, since the throttle valve 21 is opened to the predetermined opening degree C. during deceleration operation of the engine 1, the intake amount taken in the combustion

chamber **16** is increased by just that much, increasing exhaust pressure in the engine **1**, thereby amplifying the change in the flow of EGR gas. This can improve the detection property (including detection accuracy) related to failures of the EGR valve **18**.

<Third Embodiment>

A third embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the invention will be explained in detail referring to the accompanying drawings.

The third embodiment differs from the first embodiment in the processing details of failure detection. FIG. **6** is a flowchart showing one example of the processing details for detecting a failure of the EGR valve **18** in the present embodiment. The flowchart of FIG. **6** differs from the flow chart of FIG. **3** in providing the processings in Steps **300** and **310** instead of the processing in Step **100** in the flowchart of FIG. **3**.

When the processing proceeds to this routine, the ECU **50** determines in Step **300** whether or not the operating condition of the engine **1** is a steady operating condition (including a case where a vehicle is in a steady running condition). The ECU **50** can makes this determination for example based on the engine rotation speed NE, the throttle opening degree TA, and others. If NO in Step **300**, the ECU **50** immediately terminates the processing. If YES in Step **300**, the ECU **50** shifts the processing to Step **310**.

In Step **310**, the ECU **50** determines whether or not an EGR ON condition is established. Specifically, the ECU **50** judges whether or not the condition needing EGR control is established. If NO in Step **310**, the ECU **50** immediately terminates the processing. If YES in Step **310**, the ECU **50** shifts the processing to Step **110**.

According to the above control, different from the first embodiment, during steady operation of the engine **1**, the ECU **50** forcibly opens the EGR valve **18** from the valve-closed state and determines whether or not the EGR valve **18** is failed based on changes in intake amount Ga measured by the air flow meter **54**.

According to the failure detection device in the present embodiment explained above, especially different from the operations and effects in the first embodiment, during steady operation of the engine **1**, the ECU **50** forcibly opens and closes the EGR valve **18** and then determines the presence/absence of changes in intake amount Ga measured by the air flow meter **54**, thereby determining the presence/absence of a failure of the EGR valve **18**. Therefore, during steady operation of the engine **1**, it is possible to effectively detect the failure of the EGR valve **18** without providing any additional unit or means for failure detection in the low pressure loop EGR apparatus.

According to the present embodiment, furthermore, when the ECU **50** determines the EGR valve **18** is failed, the ECU **50** finds the estimated intake amount kGa during valve closing of the EGR valve **18** based on the engine rotation speed NE detected by the rotation speed sensor **52** and the throttle opening degree TA detected by the throttle sensor **23** and also finds the actual measured value of the intake amount Ga. By comparing the estimated intake amount kGac and the intake amount Ga, the ECU **50** further determines whether the EGR valve **18** is in the open-valve failure or the closed-valve failure. Herein, since the rotation speed sensor **52** and the throttle sensor **23** are arranged respectively to detect the engine rotation speed NE and the throttle opening degree TA representing the operating condition of the engine **1**, any additional unit or means for detecting a failure of the EGR valve **18** is not needed. Accordingly, it is possible to specify whether the EGR valve **18** is in the open-valve failure or the closed-valve failure without providing any separate sensor.

<Fourth Embodiment>

Next, a fourth embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the present invention will be explained in detail referring to accompanying drawings.

The fourth embodiment differs from each of the above embodiments in the processing details for failure detection. FIG. **7** is a flowchart showing one example of the processing details to detect a failure of the EGR valve **18** in this embodiment. The flowchart of FIG. **7** is identical to the flowchart of FIG. **6** in Steps **300** and **310** and different from the flowchart of FIG. **6** in the remaining processings.

When the processing proceeds to this routine, the ECU **50** determines in Step **300** whether or not the engine **1** is during steady operation and then judges in Step **310** whether or not the EGR ON condition is established. If YES in Steps **300** and **310**, the ECU **50** takes the intake amount Ga in Step **320**. In this case, since the EGR ON condition is established, the EGR valve **18** is held in a valve-open state.

In Step **330**, the ECU **50** successively determines whether or not a failure determination flag Xegrobd is "0". If NO in Step **330**, the ECU **50** terminates subsequent processings. If YES in Step **330**, the ECU **50** advances the processing to Step **340**.

In Step **340**, the ECU **50** takes the engine rotation speed NE and the throttle opening degree TA. In Step **350**, the ECU **50** finds the estimated intake amount kGao during valve opening of the EGR valve **18** based on the taken engine rotation speed NE and throttle opening degree TA. The ECU **50** can find this estimated intake amount kGao by referring to for example an estimated intake amount map shown in FIG. **8**. In this map, the estimated intake amount kGao is set larger as the engine rotation speed NE is higher and the throttle opening degree TA is larger.

In Step **360**, the ECU **50** similarly finds an estimated intake amount kGac during valve closing of the EGR valve **18** based on the engine rotation speed NE and the throttle opening degree TA. The ECU **50** can find this estimated intake amount kGac by referring to for example the estimated intake amount map shown in FIG. **4**.

In Step **370**, the ECU **50** determines whether or not the ratio of an actual measured intake amount Ga to the estimated intake amount kGao during valve opening is equal to "1±D". Herein, the term "D" is a predetermined value less than 1 to define a margin of error. If YES in Step **370**, the estimated intake amount kGao during valve opening is considered to be nearly equal to the actual measured intake amount Ga and the ECU **50** advances the processing to Step **380**. If NO in Step **370**, the estimated intake amount kGao during valve opening is not considered to be nearly equal to the actual measured intake amount Ga and the ECU **50** shifts the processing to Step **470**.

In Step **380**, the ECU **50** takes a target opening degree Tegr of the EGR valve **18**. Herein, the target opening degree Tegr is separately calculated by the ECU **50** to execute EGR control.

In Step **390**, the ECU **50** determines whether or not the taken target opening degree Tegr is smaller than a predetermined value α. If YES in Step **390**, the ECU **50** advances the processing to Step **400**. If NO in Step **390**, the ECU **50** shifts the processing to Step **410**.

In Step **400**, the ECU **50** sets a small opening degree check flag Xegropen**1** to "1". This flag Xegropen**1** is set to

"1" when the EGR valve **18** was subjected to failure check in a range where the target opening degree Tegr of the EGR valve **18** is smaller than the predetermined value α.

On the other hand, in Step **410**, the ECU **50** sets a large opening degree check flag Xegropen**2** to "1". This flag Xegropen**2** is set to "1" when the EGR valve **18** was subjected to failure check in a range where the target opening degree Tegr of the EGR valve **18** is equal to or larger than the predetermined value α.

In Step **420** subsequent to Step **400** or **410**, the ECU **50** determines whether or not both the small opening degree check flag Xegropen**1** and the large opening degree check flag Xegropen**2** are "1". If YES in Step **420**, it represents that the EGR valve **18** was subjected to check in both the region where the target opening degree Tegr is smaller than the predetermined value α and the region where the target opening degree Tegr is equal to or larger than the predetermined value α. Thus, the ECU **50** shifts the processing to Step **430**. If NO in Step **420**, it represents that the EGR valve **18** was not subjected to check in both the above regions of the target opening degree Tegr. Thus, the ECU **50** shifts the processing to Step **460**.

In Step **430**, the ECU **50** determines the EGR valve **18** to be normal. At that time, the ECU **50** can store the fact of the normality determination in a memory.

In Step **440**, the ECU **50** respectively resets the small opening degree check flag Xegropen**1** and the large opening degree check flag Xegropen**2** to "0". In Step **450**, the ECU **50** sets the failure determination flag Xegrobd to "1" and terminates subsequent processings.

In Step **460**, on the other hand, the ECU **50** suspends failure determination of the EGR valve **18** and terminates subsequent processings.

In Step **470** subsequent to Step **370**, the ECU **50** determines whether or not the ratio of the actual measured intake amount Ga to the estimated intake amount kGao during valve opening is equal to "1±E". Herein, the term "E" is a predetermined value less than 1 to define a margin of error. If YES, in Step **470**, the estimated intake amount kGao during valve opening is considered to be nearly equal to the actual measured intake amount Ga, the ECU **50** shifts the processing to Step **480**. If NO in Step **470**, the ECU **50** shifts the processing to Step **500**.

In Step **480**, the ECU **50** determines whether or not the ratio of the estimated intake amount kGac during valve closing to the actual measured intake amount Ga is not equal to "1±F". Herein, the term "F" is a predetermined value less than 1 to define a margin of error. If YES in Step **480**, the estimated intake amount kGac during valve closing is not nearly equal to the actual measured intake amount Ga and thus the ECU **50** advances the processing to Step **490**. If NO in Step **480**, the estimated intake amount kGac during valve closing is considered to be nearly equal to the actual measured intake amount Ga and thus the ECU **50** shifts the processing to Step **460**.

In Step **490**, the ECU **50** determines that the EGR valve **18** is failed in the valve open state. At that time, the ECU **50** can notify a driver of the fact of the open-valve failure determination and store this fact in a memory.

In Step **510**, the ECU **50** sets the failure determination flag Xegrobd to "1" and terminates subsequent processings.

In Step **500**, on the other hand, the ECU **50** determines that the EGR valve **18** is failed in the valve-closed state. At that time, the ECU **50** can notify a driver of the fact of the closed-valve failure determination and store this fact in a memory. Subsequently, the ECU **50** shifts the processing to Step **510** and terminates subsequent processings.

According to the above control, different from the third embodiment, the ECU **50** determines if the EGR valve **18** is failed respectively under a first condition that the target opening degree Tegr of the EGR valve **18** is equal to or larger than the predetermined value α, that is, the EGR valve **18** is open at a predetermined opening degree or more, and a second condition that the target opening degree Tegr is less than the predetermined value α, that is, the EGR valve **18** is open at less than the predetermined opening degree. When the EGR valve **18** is determined to be normal under both the first and second conditions, the ECU **50** determines that the EGR valve **18** is normal.

In the above control, different from the third embodiment, a region in which a suitable EGR rate is 20% or more is assumed. For determination of a failure of the EGR valve **18**, therefore, the ratio values "Ga/kGao" and "kGac/Ga" are adopted.

The failure detection device of the above explained embodiment provides the following operations and effects especially different from those in the third embodiment. Specifically, under the first condition that the EGR valve **18** is open at the predetermined opening degree or more (under the condition that the target opening degree Tegr is the predetermined value α or higher) and the second condition that the EGR valve **18** is open at less than the predetermined opening degree (under the condition that the target opening degree Tegr is less than the predetermined value α), the ECU **50** determines if the EGR valve **18** is failed. When the EGR valve **18** is determined to be normal under the first and second conditions, the ECU **50** determines the EGR valve **18** to be normal. Accordingly, the reliability of normality determination on the EGR valve **18** is enhanced. This enables more correct confirmation that the EGR valve **18** is normal.

According to the present embodiment, when the EGR valve **18** is determined to be failed, the ECU **50** finds both the estimated intake amount kGac during valve closing of the EGR valve **18** and the estimated intake amount kGao during valve opening of the EGR valve **18** based on the engine rotation speed NE and the throttle opening degree TA and also finds the actual measured value of the intake amount Ga. By comparing those estimated intake amount kGac and intake amount Ga and comparing those estimated intake amount kGao and intake amount Ga, the ECU **50** further determines whether the EGR valve **18** is in the open-valve failure or the closed-valve failure. This can further specify whether the EGR valve **18** is in the open-valve failure or the closed-valve failure.

<Fifth Embodiment>

A fifth embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the present invention will be explained in detail referring to accompanying drawings.

The fifth embodiment differs from each of the above embodiments in the processing details for failure detection. FIG. **9** is a flowchart showing one example of the processing details to detect a failure of the EGR valve **18** in the present embodiment.

When the processing proceeds to this routine, in Step **800**, the ECU determines whether or not the operating condition of the engine **1** is a steady operating condition (including the case where a vehicle is in a steady running state). If NO in Step **800**, the ECU **50** immediately terminates the processing. If YES in Step **800**, the ECU **50** shifts the processing to Step **810**.

In Step **810**, the ECU **50** determines whether or not the EGR ON condition is established. If NO in Step **810**, the

ECU **50** immediately terminates the processing. If YES in Step **810**, the ECU **50** shifts the processing to Step **820**.

In Step **820**, the ECU **50** determines whether or not the failure determination flag Xegrobd is "0". If No in Step **820**, the ECU **50** immediately terminates the processing. If YES in Step **820**, the ECU **50** shifts the processing to Step **830**.

In Step **830**, the ECU **50** takes a first air-fuel ratio AF (AF**1**) based a detection value of the air-fuel ratio sensor **55**.

In Step **840**, the ECU **50** controls the EGR valve **18** to close. Specifically, the ECU **50** forcibly closes the EGR valve **18** remaining open under the EGR ON condition.

In Step **845**, the ECU **50** then waits for a lapse of predetermined time T**1** from closing of the EGR valve **18**, and shifts the processing to Step **850**. In Step **850**, the ECU **50** takes a second air-fuel ratio AF (AF**2**) based on a detection value of the air-fuel ratio sensor **55**.

In Step **855**, the ECU **50** determines whether or not a difference between the first air-fuel ratio AF**1** and the second air-fuel ratio AF**2** is larger than a predetermined value J. In other words, the ECU **50** determines whether or not the air-fuel ratio AF deviates to a rich side immediately after the EGR valve **18** is closed.

Herein, FIG. **10** shows a time chart showing behaviors of (a) opening degree of the EGR valve **18**, (b) EGR rate, (c) intake amount Ga, and (d) air-fuel ratio AF in the case where the EGR valve **18** is normal. In FIG. **10**, at time t**1**, when the EGR valve **18** is closed from the valve open state as shown in (a), the EGR rate at the outlet **17***a* of the EGR passage **17** rapidly decreases as indicated by a thick line in (b), the intake amount Ga measured by the air flow meter **54** increases as indicated by a thick line in (c), and the air-fuel ratio AF deviates to a rich side as indicated in (d). Then, at slightly later time t**2** in FIG. **10**, the EGR rate in the combustion chamber **16** rapidly decreases as indicated by a broken line in (b), the intake amount Ga in the combustion chamber **16** increases as indicated by a broken line in (c) and the air-fuel ratio AF deviated to the rich side returns to an original level as indicated by a thick line in (d). In this manner, since increasing of the intake amount Ga in the combustion chamber **16** gets delayed, the air-fuel ratio AF temporarily deviates to a rich side immediately after the EGR valve **18** is forcibly closed from the valve open state. By checking the deviation of the air-fuel ratio AF to the rich side, it is ascertained that the EGR valve **18** is normally closed from the valve-open state. This rich-side deviation of the air-fuel ratio AF is determined based on that a difference between the first air-fuel ratio AF **1** taken before the time t**1** and the second air-fuel ratio AF**2** taken after a lapse of the predetermined time T**1** from when the time t**1** is larger than the predetermined value J as shown in FIG. **10** (*d*).

Returning to FIG. **9**, if YES in Step **855**, the ECU **50** determines in Step **860** that the EGR valve **18** is normal. At that time, the ECU **50** can store the fact of the normality determination in a memory.

On the other hand, if NO in **855**, the ECU **50** determines in Step **870** that the EGR valve **18** is failed. At that time, the ECU **50** can notify a driver of the fact of the failure determination or store this fact in a memory.

In Step **880** subsequent to Step **860** or **870**, subsequently, the ECU **50** returns the EGR valve **18** to normal control. In other words, the ECU **50** returns the EGR valve **18** from the forcibly valve-closed state to the previous valve-open state.

In Step **890**, the ECU **50** sets the failure determination flag Xegrobd to "1" and then terminates the processing.

According to the above control, different from the third and fourth embodiments, the ECU **50** forcibly opens and closes the EGR valve **18** during steady operation of the engine **1** and determines whether or not the EGR valve **18** is failed based on changes in air-fuel ratio AF detected by the air-fuel ratio sensor **55**. To be concrete, immediately after forcibly closing the EGR valve **18** from the valve-open state, the ECU **50** determines whether or not the air-fuel ratio AF deviates to a rich side. The ECU **50** judges that the EGR valve **18** is normal when the rich-side deviation is present, whereas the ECU **50** judges that the EGR valve **18** is failed when the rich-side deviation is absent.

According to the failure detection device of the present embodiment explained above, during steady operation of the engine **1**, the ECU **50** forcibly closes the EGR valve **18** and determines the presence/absence of changes in air-fuel ratio AF detected by the air-fuel ratio sensor **55**, thereby determining the presence/absence of a failure of the EGR valve **18**. Herein, the air-fuel ratio sensor **55** is used to detect the air-fuel ratio AF representing the operating condition of the engine **1** and thus no additional unit or means to detect a failure of the EGR valve **18** is needed. Accordingly, during steady operation of the engine **1**, it is possible to effectively detect the failure of the EGR valve **18** without providing any additional unit or means for failure detection in the low pressure loop exhaust recirculation apparatus.

<Sixth Embodiment>

A sixth embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the present invention will be explained in detail referring to accompanying drawings.

The sixth embodiment differs from each of the above embodiments in the processing details for failure detection. FIG. **11** is a flowchart showing one example of the processing details to detect a failure of the EGR valve **18** in the present embodiment. The flowchart of FIG. **11** is identical to the flowchart of FIG. **9** in Steps **800** to **855** and **880** and different from the flowchart of FIG. **9** in remaining Steps **865**, **875**, **876**, **879**, and **900** to **990**.

When the processing proceeds to this routine, the ECU **50** executes the processings in the Steps **800** to **855** in a similar manner to the flowchart of FIG. **9**. If YES in Step **855**, the ECU **50** shifts the processing to Step **865**. If NO in Step **855**, the ECU **50** shifts the processing to Step **875**.

In Step **865**, the ECU **50** temporarily determines that the EGR valve **18** is normal ("normality temporary determination") and sets a normality temporary determination flag XAFR to "1". Herein, the normality temporary determination represents that the EGR valve **18** is temporarily determined to be normal, differently from that the EGR valve **18** is conclusively determined to be normal ("normality conclusive determination") which will be mentioned later.

On the other hand, in Step **875**, the ECU **50** temporarily determines that the EGR valve **18** is failed ("failure temporary determination") and sets the normality temporary determination flag XAFR to "0". Herein, the failure temporary determination represents that the EGR valve **18** is temporarily determined to be failed, differently from that the EGR valve **18** is conclusively determined to be failed ("failure conclusive determination") which will be mentioned later.

In Step **876**, the ECU **50** waits for a lapse of a predetermined time T**2** (>T**1**) from closing of the EGR valve **18**, and then shifts the processing to Step **879**. In Step **879**, the ECU **50** takes a third air-fuel ratio AF (AF**3**) based on a detection value of the air-fuel ratio sensor **55**.

In Step **880**, the ECU **50** then returns the EGR valve **18** to normal control.

Specifically, the ECU **50** returns the EGR valve **18** from the forcibly closed state to the previous open state.

In Step **900**, the ECU **50** waits for a lapse of a predetermined time T**1** from opening of the EGR valve **18**, and then shifts the processing to Step **910**. In Step **910**, the ECU **50** takes a fourth air-fuel ratio AF (AF**4**) based on a detection value of the air-fuel ratio sensor **55**.

In Step **920**, the ECU **50** determines whether or not a difference between the fourth air-fuel ratio AF**4** and the third air-fuel ratio AF**3** is larger than a predetermined value K. Specifically, the ECU **50** determines whether or not the air-fuel ratio AF deviates to a lean side immediately after the EGR valve **18** is opened.

Herein, at time t**3** in FIG. **10**, when the EGR valve **18** is opened from the valve-closed state to the previous open state as shown in (a), the EGR rate at the outlet **17***a* of the EGR passage **17** rises as indicated by the thick line in (b), the intake amount Ga measured by the air flow meter **54** decreases as indicated by the thick line in (c), and the air-fuel ratio AF temporarily deviates to a lean side as indicated by the thick line in (d). Thereafter, at slightly later time t**4** in FIG. **10**, the EGR rate in the combustion chamber **16** rapidly increases as indicated by the broken line in (b), the intake amount Ga of the combustion chamber **16** decreases as indicated by the broken line in (c), and the air-fuel ratio AF deviated to the lean side returns to an original level as indicated by the thick line in (d). In this manner, since decreasing of the intake amount Ga in the combustion chamber **16** gets delayed, the air-fuel ratio AF temporarily deviates to a lean side immediately after the EGR valve **18** is opened from the valve-closed state to the previous valve-open state. By checking the deviation of the air-fuel ratio AF to the lean side, it is ascertained that the EGR valve **18** is normally opened from the valve-closed state. This lean-side deviation of the air-fuel ratio AF is determined based on that a difference between the fourth air-fuel ratio AF**4** taken after a lapse of the predetermined time T**1** from the time t**3** and the third air-fuel ratio AF**3** taken before the time t**3** is larger than the predetermined value K as shown in FIG. **10** (*d*).

Returning to FIG. **11**, if YES in Step **920**, the ECU **50** determines in Step **930** whether or not the normality temporary determination flag XAFR is "1". If YES in Step **930**, the ECU **50** shifts the processing to Step **940**. If NO in Step **930**, the ECU **50** shifts the processing to Step **990**.

In Step **940**, the ECU **50** conclusively determines that the EGR valve **18** is normal. At that time, the ECU **50** can store the fact the normality conclusive determination in a memory.

If NO in Step **920**, on the other hand, the ECU **50** determines in Step **970** whether or not the normality temporary determination flag XAFR is "0". If YES in Step **970**, the ECU **50** shifts the processing to Step **980**. If NO in Step **970**, the ECU **50** shifts the processing to Step **990**.

In Step **980**, the ECU **50** conclusively determines that the EGR valve **18** is failed. At that time, the ECU **50** can notify a driver of the fact of the failure determination or store this fact in a memory.

In Step **950** subsequent to Step **940** or **980**, the ECU **50** sets the failure determination flag Xegrobd to "1". In Step **960**, the ECU **50** then resets the normality temporary determination flag XFAR to "0" and terminates subsequent processings.

On the other hand, in Step **990** subsequent to Step **930** or **970**, the ECU **50** suspends the failure determination of the EGR valve **18** and advances the processing to Step **960**.

According to the above control, different from the fifth embodiment, the ECU **50** forcibly closes the EGR valve **18** from the valve-open state and then immediately determines whether or not the air-fuel ratio AF deviates to a rich side. The ECU **50** thus temporarily determines the normality when the rich-side deviation of the air-fuel ratio AF is present, while temporarily determines the failure when the rich-side deviation is absent. Subsequently, the ECU **50** forcibly opens the EGR valve **18** from the valve-closed state and then immediately determines whether or not the air-fuel ratio AF deviates to a lean side. When the normality is temporarily determined and the lean-side deviation is present, the ECU **50** conclusively determines the EGR valve **18** to be normal. When the failure is temporarily determined and the lean-side deviation is absent, the ECU **50** conclusively determines the EGR valve **18** to be failed.

The failure detection device of the present embodiment explained above provides the following operations and effects different from those in the fifth embodiment. Specifically, in the presence of the rich-side deviation of the air-fuel ratio AF, the EGR valve **18** is temporarily determined to be normal. In the absence of the rich-side deviation of the air-fuel ratio AF, the EGR valve **18** is temporarily determined to be failed. When the normality is temporarily determined and the air-fuel ratio AF deviates to the lean side, the EGR valve **18** is conclusively determined to be normal. When the failure is temporarily determined and the air-fuel ratio AF does not deviate to the lean side, the EGR valve **18** is conclusively determined to be failed. This makes it possible to more accurately detect the EGR valve **18** to be failed or to be normal.

<Seventh Embodiment>

A seventh embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the present invention will be explained referring to accompanying drawings.

The seventh embodiment differs from the sixth embodiment in the processing details for failure detection. FIG. **12** is a flowchart showing one example of the processing details to detect a failure of the EGR valve **18** in the present embodiment. The flowchart of FIG. **12** is different from the flowchart of FIG. **11** in Steps **846** and **847** provided instead of the processing in Step **845** in the flowchart of FIG. **11**, and Steps **877** and **878** instead of the processing in Step **876** in the flowchart of the FIG. **11**, and Steps **885**, **905**, and **906** instead of the processing in Step **900** in the flowchart of FIG. **11**.

When the processing proceeds to this routine, the ECU **50** executes the processings in Steps **800** to **840** in a similar manner to those in the flowchart of FIG. **11**. In Step **846**, the ECU **50** takes an accumulated intake amount TGaoff after the EGR valve **18** is closed. The ECU **50** can find this accumulated intake amount TGaoff after valve closing by sequentially accumulating intake amounts Ga obtained after closing the EGR valve **18**. In Step **847**, the ECU **50** waits for the accumulated intake amount TGaoff after valve closing becomes larger than a predetermined value Tga**1**, and shifts the processing to Step **850**.

Thereafter, the ECU **50** executes the processings in Steps **850** to **875** and, in Step **877**, waits for the accumulated intake amount TGaoff after valve closing becomes larger than a predetermined value Tga**2**, and then shift the processing to Step **878**. In Step **878**, the ECU **50** resets the accumulated intake amount TGaoff after valve closing to "0".

Subsequently, the ECU **50** executes the processing in the Steps **879** and **880** and then in Step **885** takes an accumulated intake amount TGaon after the EGR valve **18** is opened. The ECU **50** can find this accumulated intake amount TGaon after valve opening by sequentially accumulating the intake amounts Ga obtained after opening the EGR valve **18** in Step **880**. In Step **905**, the ECU **50** waits for that the accumulated intake amount TGaon after valve

opening becomes larger than the predetermined value Tga**1** and then shifts the processing to Step **906**. In Step **906**, the ECU **50** resets the accumulated intake amount TGaon after valve opening to "0". Subsequently, the ECU **50** executes the processings in Steps **910** to **990**.

FIG. **13** is a time chart showing behaviors of (a) opening degree of the EGR valve **18**, (b) EGR rate, (c) intake amount Ga, (d) accumulated intake amount TGaoff after valve closing and accumulated intake amount TGaon after valve opening of the EGR valve **18**, and (e) air-fuel ratio AF in the case of the EGR valve **18** being normal. Regarding the timing to take the air-fuel ratios AF**2** and AF**3** after closing the EGR valve **18** and take the air-fuel ratio AF**4** after opening the EGR valve **18**, the ECU **50** in the sixth embodiment determines respective timings at the time when the predetermined time T**1** or T**2** has elapsed as shown in FIG. **10**. According to the above control in the present embodiment, it is determined at the time when the accumulated intake amount TGaoff after valve closing and the accumulated intake amount TGaon after valve opening exceed the predetermined values Tga**1** and Tga**2** respectively as shown in FIG. **13**. The present embodiment can therefore also provide similar operations and effects to those in the sixth embodiment.

<Eighth Embodiment>

An eighth embodiment embodying a failure detection device for an exhaust recirculation apparatus of a supercharger-equipped engine according to the present invention will be explained in detail referring to accompanying drawings.

The eighth embodiment differs from each of the above embodiments in the configuration of an engine system and the processing details for failure detection. FIG. **14** is a schematic configuration view of the engine system including an EGR apparatus of a supercharger-equipped engine in the present embodiment. The engine system in the present embodiment differs from that shown in FIG. **1** in a fresh-air induction passage **41** and a fresh-air induction valve **42** which are additionally provided. The fresh-air induction passage **41** has an inlet **41***a* connected to the intake passage **3** upstream of the outlet **17***a* of the EGR passage **17** and an outlet **41***b* connected to the intake passage **3** downstream of the throttle valve **21** and upstream of the surge tank **3***a*. The fresh-air induction valve **42** is an electrically operated valve provided in the fresh-air induction passage **41** and is controlled to regulate a flow rate of fresh air in the passage **41**.

FIGS. **15** and **16** are flowcharts respectively showing one examples of the processing details to detect a failure of the EGR valve **18** in the present embodiment. When the processing proceeds to this routine in FIG. **15**, the ECU **50** determines in Step **1000** whether or not a failure determination flag Xegrobd is "0". If NO in Step **1000**, the ECU **50** returns the processing again to Step **1000**. If YES in Step **1000**, the ECU **50** advances to the processing to Step **1010**.

In Step **1010**, the ECU **50** determines whether or not the engine **1** is at idle. The ECU **50** can make this determination based on an engine rotation speed NE and a throttle opening degree TA and others. During idle operation of the engine **1**, the EGR valve **18** is controlled to close. If YES in Step **1010**, the ECU **50** shifts the processing to Step **1020**. If NO in Step **1010**, the ECU **50** advances the processing to Step **1040**.

In Step **1020**, the ECU **50** determines whether or not combustion is stable. Specifically, the ECU **50** determines whether or not the combustion of air-fuel mixture in the combustion chamber **16** is stable. The ECU **50** makes this determination based on changes in combustion state. Herein, the changes in combustion state reflects in the rotation speed of the engine **1**. In other words, when the combustion state is stable, the engine rotation speed NE, that is, the rotation angle of a crank shaft **1***a* exhibits stable cyclic changes. In contrast, when the combustion is unstable, the rotation angle of the crank shaft **1***a* exhibits unstable cyclic changes. Accordingly, the ECU **50** can make this determination based on the engine rotation speed NE detected by the rotation speed sensor **52**. If NO in Step **1020**, the ECU returns the processing to Step **1000**. If YES in Step **1020**, the ECU **50** advances the processing to Step **1030**. Herein, during idle operation of the engine **1**, EGR gas (EGR rate) is less taken in the combustion chamber **16** even when the EGR valve **18** remaining open is failed. Thus, the combustion of air-fuel mixture does not get unstable due to the influence of EGR gas. This makes it difficult to determine open-valve failure of the EGR valve **18** based on the changes in combustion state of air-fuel mixture. However, from the stable combustion of air-fuel mixture during idle operation, it is ascertained that fuel supply by the injectors **25** and others (a fuel supply device) and ignition operation by the ignition plugs **29** and others (an ignition device) are normal.

In Step **1030**, the ECU **50** sets an idle stability flag Xidle to "1" and returns the processing to Step **1000**. Herein, the idle stability flag Xidle is set to "1" in a case where the combustion is stable and set to "0" in a case where the combustion is unstable.

On the other hand, in Step **1040** subsequent to Step **1010**, the ECU **50** determines whether or not a largely open-valve non-failure determination flag XegrOobd is "0". Herein, this largely open-valve non-failure determination flag XegrOobd is set to "1" when it is completely determined that the EGR valve **18** is held largely open and is not failed, while the flag XegrOobd is set to "0" when this determination is not completed. If NO in Step **1040**, the ECU **50** returns the processing to Step **1000**. If YES in Step **1040**, the ECU **50** shifts the processing to Step **1050**.

In Step **1050**, the ECU **50** takes an intake amount Ga. In Step **1060**, the ECU **50** determines whether or not the taken intake amount Ga is larger than a predetermined value G**1** and smaller than a predetermined value G**2**(G**1**<G**2**). If NO in Step **1060**, the ECU **50** returns the processing to Step **1000**. If YES in Step **1060**, the ECU **50** considers that the intake amount Ga is in a moderate range and the exhaust pressure of the engine **1** is in a rising range, and shifts the processing to Step **1070**.

In Step **1070**, the ECU **50** determines whether or not the idle stability flag Xidle to "1". If NO in Step **1070**, the ECU **50** returns the processing to Step **1000**. If YES in Step **1070**, the ECU **50** shifts the processing to Step **1080**.

In Step **1080**, in a similar manner to the above, the ECU **50** determines whether or not the combustion of air-fuel mixture is stable. At that time, since the determination result in Step **1070** is affirmative, it is ascertained that combustion has been stable during idle operation, that is, the fuel supply device and the ignition device are normal. Thus, the combustion being unstable in Step **1080** represents that EGR gas is accidentally taken in the combustion chamber **16**, resulting in a high EGR rate, that is, the EGR valve **18** is failed in an open state. If NO in Step **1080**, the ECU **50** shifts the processing to Step **1130**. If YES in Step **1080**, the ECU **50** advances the processing to Step **1090**.

In Step **1130**, because of the unstable combustion, the ECU **50** determines that the EGR valve **18** is failed in an open state. At that time, the ECU **50** can notify a driver of the fact of the open-valve failure determination or store this fact in a memory.

On the other hand, in Step **1090**, the ECU **50** determines whether or not the EGR ON condition is established. If NO in Step **1090**, the ECU **50** returns the processing to Step **1000**. If YES in Step **1090**, the ECU **50** shifts the processing to Step **1100**.

In Step **1100**, the ECU **50** determines whether or not a closed-valve non-failure determination flag XegrCobd is "1". Herein, this flag XegrCobd is set to "1" when it is completely determined that the EGR valve **18** held in a valve-closed state is not failed and set to "0" when this determination is not completed. If NO in Step **1100**, the ECU **50** shifts the processing to Step **1140**. If YES in Step **1100**, the ECU **50** advances the processing to Step **1110**.

In Step **1140**, the ECU **50** sets the largely open-valve non-failure determination flag XegrOobd to "1" and returns the processing to Step **1000**.

In Step **1110**, on the other hand, the ECU **50** determines that the EGR valve **18** is normal. At that time, the ECU **50** can store the fact of the normality determination in the memory.

In Step **1120** subsequent to Step **1130** or **1110**, the ECU **50** sets the failure determination flag Xegrobd to "1" and returns the processing to Step **1000**.

Next, the flowchart of FIG. **16** will be explained. When the processing proceeds to this routine, the ECU **50** determines in Step **1200** whether or not the failure determination flag Xegrobd is "0". If NO in Step **1200**, the ECU **50** returns the processing to Step **1200**. If YES in Step **1200**, the ECU **50** advances the processing to Step **1210**.

In Step **1210**, the ECU **50** determines whether or not the closed-valve non-failure determination flag XegrCobd is "0". If NO in Step **1210**, the ECU **50** returns the processing to Step **1200**. If YES in Step **1210**, the ECU **50** shifts the processing to Step **1220**.

In Step **1220**, the ECU **50** determines whether or not the engine is in a state immediately after deceleration from EGR ON or whether or not it is the EGR valve **18** is in a state immediately after it is closed. If NO in Step **1220**, the ECU **50** returns the processing to Step **1200**. If YES in Step **1220**, the ECU **50** shifts the processing to Step **1230**.

In Step **1230**, the ECU **50** controls the fresh-air induction valve **42** to close. That is, the ECU **50** forcibly closes the fresh-air induction valve **42** from a valve-open state. This blocks the introduction of fresh air to the surge tank **3***a* through the fresh-air induction passage **41**.

In Step **1240**, the ECU **50** then corrects the valve opening of the throttle valve **21**. Herein, when the fresh-air induction valve **42** is closed, the intake amount to be introduced in the combustion chamber **16** decreases. The ECU **50** therefore controls the electronic throttle device **14** to supplement an amount corresponding to such a decrease in intake amount to open the throttle valve **21** by a necessary degree.

In Step **1250**, the ECU **50** determines whether or not the combustion is stable. Herein, in the case of the EGR valve **18** being normal, at the time immediately after engine deceleration from EGR ON (immediately after closing of the EGR valve **18**), EGR gas supplied until just before is supplied to the combustion chamber **16**. Further, the fresh-air induction valve **42** is closed, thereby blocking introduction of fresh air to the combustion chamber **16**. Accordingly, a percentage of EGR gas (EGR rate) in the combustion chamber **16** becomes temporarily high, causing unstable combustion of a fuel. In contrast, in the case of the EGR valve **18** failed in a closed state, even when the EGR valve **18** is closed in accordance with the engine deceleration from EGR ON and the fresh-air induction valve **42** is forcibly closed, the EGR rate in the combustion chamber **16** does not change and thus the combustion of a fuel remains stable. The ECU **50** therefore determines whether or not the combustion is stable based on changes in combustion state to determine whether or not the EGR valve **18** is in the closed-valve failure state. If YES in Step **1250**, the ECU **50** shifts the processing to Step **1260**. If NO in Step **1250**, the ECU **50** advances the processing to Step **1280**.

In Step **1260**, because of stable combustion, the ECU **50** determines that the EGR valve **18** is failed in a closed state. At that time, the ECU **50** can notify a driver of the fact of the closed-valve failure determination or store this fact in the memory.

In Step **1270**, thereafter, the ECU **50** sets the failure determination flag Xegrobd to "1" and returns the processing to Step **1200**.

On the other hand, in Step **1280**, because of unstable combustion, the ECU **50** controls the fresh-air induction valve **42** to return. Specifically, the ECU **50** returns the fresh-air induction valve **42** from the valve-closed state to the valve-open state. This allows re-start of introduction of fresh air to the surge tank **3***a*. In Step **1290**, furthermore, the ECU **50** stops correction to open the throttle valve **21**.

In Step **1300**, the ECU **50** determines whether or not the largely open-valve non-failure determination flag XegrOobd is "1". If NO in Step **1300**, the ECU **50** shifts the processing to Step **1320**. If YES in Step **1300**, the ECU **50** shifts the processing to Step **1310**.

In Step **1320**, the ECU **50** sets the closed-valve non-failure determination flag XegrCobd to "1" and returns the processing to Step **1200**.

In the Step **1310**, on the other hand, the ECU **50** judges the EGR valve **18** to be normal. At that time, the ECU **50** can store the fact of the normality determination in the memory. The ECU **50** then shifts the processing to Step **1270**.

According to the above control, the ECU **50** determines if the EGR valve **18** is failed based on changes in fuel combustion state of the fuel in the combustion chamber **16** supplied by the injectors **25** while the engine **1** is in a predetermined operating condition. To be specific, the ECU **50** determines the changes in combustion state of the fuel in the combustion chamber **16** during idle operation of the engine **1** based on the engine rotation speed NE detected by the rotation speed sensor **52** and determines the open-valve failure of the EGR valve **18**. The ECU **50** causes the fresh-air induction valve **42** to close from the valve-open state immediately after the engine **1** enters the deceleration operation from EGR ON (the EGR valve **18** is closed), and judges the changes in fuel combustion state in the combustion chamber **16** based on the engine rotation speed NE detected by the rotation speed sensor **52** to determine the closed-valve failure of the EGR valve **18**.

According to the failure detection device of the present embodiment explained above, similar to the above embodiments, during a predetermined operating condition of the engine **1**, the normal EGR valve **18** is controlled, thereby causing changes in a flow of EGR gas flowing from the EGR passage **17** to the intake passage **3**, changing the intake amount Ga flowing in the intake passage **3**, thus changing the combustion state of the fuel in the combustion chamber **16**. If the EGR valve **18** is in failure, even when the EGR valve **18** is controlled, the flow of EGR gas is not changed as expected, the flow amount Ga of intake air flowing in the intake passage **3** is also not changed as expected, and a predicted change does not appear in the combustion state. Accordingly, while the engine **1** is in a predetermined operating state, the ECU **50** determines the presence/absence of changes in combustion state to determine the

presence/absence of a failure of the EGR valve **18**. This enables effective detection of a failure of the EGR valve **18** without separately providing any additional unit or means for failure detection in the low pressure loop exhaust recirculation apparatus.

To be more specific, during idle operation of the engine **1**, the ECU **50** determines the presence/absence of changes in combustion state based on the engine rotation speed NE detected by the rotation speed sensor **52** to determine the presence/absence of open-valve failure of the EGR valve **18**. Herein, the rotation speed sensor **52** is used to detect the engine rotation speed NE representing the operating condition of the engine **1** and thus no additional unit or means is necessary to detect failure of the EGR valve **18**. This enables effective detection of a failure of the EGR valve **18** during idle operation of the engine **1** without separately providing any additional unit or means for failure detection in the low pressure loop exhaust recirculation apparatus.

Furthermore, the fresh-air induction valve **42** is closed from the valve-open state immediately after the engine **1** enters deceleration operation from EGR ON (the EGR valve **18** is closed) and the changes in combustion state of a fuel in the combustion chamber **16** are judged based on the engine rotation speed NE detected by the rotation speed sensor **52**, thereby determining the presence/absence of closed-valve failure of the EGR valve **18**. This enables effective detection of a failure of the EGR valve **18** during deceleration operation of the engine **1** without separately providing any additional unit or means for failure detection in the low pressure loop exhaust recirculation apparatus.

The present invention is not limited to the above embodiments and may be embodied in other specific forms without departing from the essential characteristics thereof.

In the fifth and sixth embodiments, it is arranged to detect a failure of the EGR valve **18** based on the presence/absence of the rich-side deviation and the lean-side deviation of the air-fuel ratio AF. As an alternative, in an engine system configured to stoiciometrically control the air-fuel ratio AF, it may be arranged to detect a failure of an EGR valve based on the presence/absence of fuel correction in order to maintain the air-fuel ratio AF at stroiciometry. FIG. **17** is a time chart showing behaviors of (a) air-fuel ratio AF and (b) fuel correction in a case where the EGR valve is normal. In FIG. **17**, in a period from time t**1** to time t**2**, it is determined that a rich-side deviation is present when a difference between "correction **1** (C**1**)" and "correction **2** (C**2**)" which are values for fuel correction is larger than a predetermined value H. In a period from time t**3** to time t**4**, it is determined that a lean-side deviation is present when a difference between "correction **4** (C**4**)" and "correction **3** (C**3**)" which are values for fuel correction is larger than a predetermined value I.

In each of the above embodiments, the failure detection device of the invention is embodied in a gasoline engine system but may also be embodied in a diesel engine.

INDUSTRIAL APPLICABILITY

The present invention is utilizable in for example a vehicle engine irrespective of a gasoline engine or a diesel engine.

Reference Signs List

1	Engine
3	Intake passage
3a	Surge tank
5	Exhaust passage
7	Supercharger
8	Compressor
9	Turbine
10	Rotary shaft
14	Electronic throttle device (Intake amount regulating unit)
16	Combustion chamber
17	EGR passage (Exhaust recirculation passage)
17a	Outlet
17b	Inlet
18	EGR valve (Exhaust recirculation valve)
21	Throttle valve
23	Throttle sensor (Opening degree detecting unit)
25	Injector (Fuel supply unit)
41	Fresh-air induction passage
42	Fresh-air induction valve
50	ECU (Failure determining unit)
52	Rotation speed sensor (Rotation speed detecting unit, Combustion state detecting unit)
54	Air flow meter (Intake amount measuring unit)
55	Air-fuel ratio sensor (Air-fuel ratio detecting unit)

The invention claimed is:

1. A failure detection device for an exhaust recirculation apparatus of an engine with a supercharger,

the engine including an intake passage, an exhaust passage, and an injector configured to supply fuel to a combustion chamber, the intake passage being provided with an intake regulating valve configured to regulate an intake amount of air flowing in the intake passage,

the supercharger including: (i) a compressor disposed in the intake passage upstream of the intake regulating valve, (ii) a turbine disposed in the exhaust passage, and (iii) a rotary shaft connecting the compressor and the turbine to integrally rotate,

the exhaust recirculation apparatus including: (i) exhaust recirculation passage configured to allow part of exhaust gas discharged from the combustion chamber of the engine to the exhaust passage to flow as exhaust recirculation gas to the intake passage to return to the combustion chamber, and (ii) an exhaust recirculation valve configured to regulate a flow of the exhaust recirculation gas in the exhaust recirculation passage, the exhaust recirculation passage having an inlet connected to the exhaust passage downstream of the turbine and an outlet connected to the intake passage upstream of the compressor,

the failure detection device being provided in the exhaust recirculation apparatus of the engine, the failure detection device comprising:

an air flow meter configured to measure the intake amount of air flowing in the intake passage;

a rotation speed sensor configured to detect a rotation speed of the engine;

a throttle sensor configured to detect an opening degree of the intake regulating valve; and

an electronic control unit configured to:

open and close the exhaust recirculation valve based on a predetermined operating condition;

determine a failure in the exhaust recirculation valve based on changes in the intake amount measured by the air flow meter when the exhaust recirculation valve is opened or closed;

when the failure is determined in the exhaust recirculation valve, calculate: (i) an estimated value of the intake amount based on (1) the rotation speed detected by the rotation speed sensor, and (2) the opening degree detected by the throttle sensor, and (ii) an actual measured value of the intake amount by the air flow meter and

determine whether the failure of the exhaust recirculation valve occurred in an open state of the exhaust recirculation valve or a closed state of the exhaust recirculation valve by comparing the estimated value and the actual measured value.

2. The failure detection device according to claim **1**, wherein when the engine is in a deceleration operation when supply of the fuel by the injector is cut off, the eletronic control unit is configured to: (i) forcibly open and close the exhaust recirculation valve, and (ii) determine that the exhaust recirculation valve is failed based on changes in the intake amount measured by the air flow meter.

3. The failure detection device according to claim **1**, wherein when the engine is in a deceleration operation and the supply of the fuel by the injector is cut off, the electronic control unit is configured to: (i) forcibly close the exhaust recirculation valve from a valve open state and forcibly open the intake regulating valve to a predetermined opening degree, and (ii) determine the failure in the exhaust recirculation valve based on changes in the intake amount measured by the air flow meter.

4. The failure detection device according to claim **1**, wherein when the engine is in a steady operation, the electronic control unit is configured to: (i) forcibly open and close the exhaust recirculation valve, and (ii) determine the failure in the exhaust recirculation valve based on changes in the intake amount measured by the air flow meter.

5. The failure detection device according to claim **1**, wherein when the engine is in a steady operation, the electronic control unit is programmed to: (i) determine the failure in the exhaust recirculation valve under: (1) a first condition in which the exhaust recirculation valve is open at a predetermined opening degree or more, and (2) a second condition in which the exhaust recirculation valve is open at less than the predetermined opening degree, and (ii) determine that the exhaust recirculation valve is normal when the failure of the exhaust recirculation valve is not determined under both the first condition and the second condition.

6. The failure detection device according to claim **1**, further including an air-fuel ratio sensor configured to detect an air-fuel ratio between air and fuel supplied to the combustion chamber in order to detect an operating condition of the engine, wherein

when the engine is in a steady operation, the electronic control unit is configured to: (i) forcibly open and close the exhaust recirculation valve, and (ii) determine the failure of the exhaust recirculation valve based on changes in the air-fuel ratio detected by the air-fuel ratio sensor.

7. A failure detection device for an exhaust recirculation apparatus of an engine with a supercharger,

the engine including an intake passage, an exhaust passage, and an injector configured to supply fuel to a combustion chamber, the intake passage being provided with an intake regulating valve configured to regulate an intake amount of air flowing in the intake passage,

the supercharger including: (i) a compressor disposed in the intake passage upstream of the intake regulating valve, (ii) a turbine disposed in the exhaust passage, and (iii) a rotary shaft connecting the compressor and the turbine to integrally rotate,

the exhaust recirculation apparatus including: (i) an exhaust recirculation passage configured to allow part of exhaust gas discharged from the combustion chamber of the engine to the exhaust passage to flow as exhaust recirculation gas to the intake passage to return to the combustion chamber, and (ii) an exhaust recirculation valve configured to regulate a flow of the exhaust recirculation gas in the exhaust recirculation passage, the exhaust recirculation passage having an inlet connected to the exhaust passage downstream of the turbine and an outlet connected to the intake passage upstream of the compressor,

the failure detection device being provided in the exhaust recirculation apparatus of the engine, the failure detection device comprising:

an air flow meter configured to measure the intake amount of air flowing in the intake passage;

a rotation speed sensor configured to detect a combustion state of the fuel in the combustion chamber;

a throttle sensor configured to detect an opening degree of the intake regulating valve; and

an electronic control unit configured to:

determine a failure of the exhaust recirculation valve based on changes in a combustion state of the fuel in the combustion chamber supplied by the injector while the engine is in a predetermined operating condition;

when the failure is determined in the exhaust recirculation valve, calculate: (i) an estimated value of the intake amount based on (1) the combustion state detected by the rotation speed sensor, and (2) the opening degree detected by the throttle sensor, and (ii) an actual measured value of the intake amount by the air flow meter; and

determine whether the failure of the exhaust recirculation valve occurred in an open state of the exhaust recirculation valve or a closed state of the exhaust recirculation valve by comparing the estimated value and the actual measured value.

8. The failure detection device according to claim **7**, wherein when the engine is during idle operation, the electronic control unit is configured to determine the failure of the exhaust recirculation valve based on changes in combustion state of the fuel detected by the rotation speed sensor.

9. The failure detection device according to claim **7**, further comprising:

a fresh-air induction passage configured to introduce fresh air to the intake passage downstream of the intake regulating value; and

a fresh-air induction valve configured to regulate fresh air flowing in the fresh-air induction passage, wherein

the electronic control unit is configured to determine the failure of the exhaust recirculation valve based on changes in the combustion state of the fuel detected by the rotation speed sensor when the fresh-air induction valve is closed from a valve-open state immediately after the engine enters deceleration operation.

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